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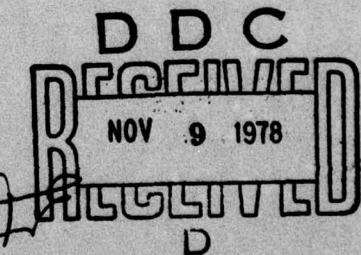
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## Steady-State Multi-Ion Disturbed D-Region Model

WILLIAM SWIDER  
CAROL I. FOLEY

15 June 1978

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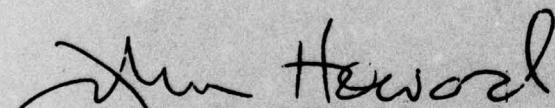
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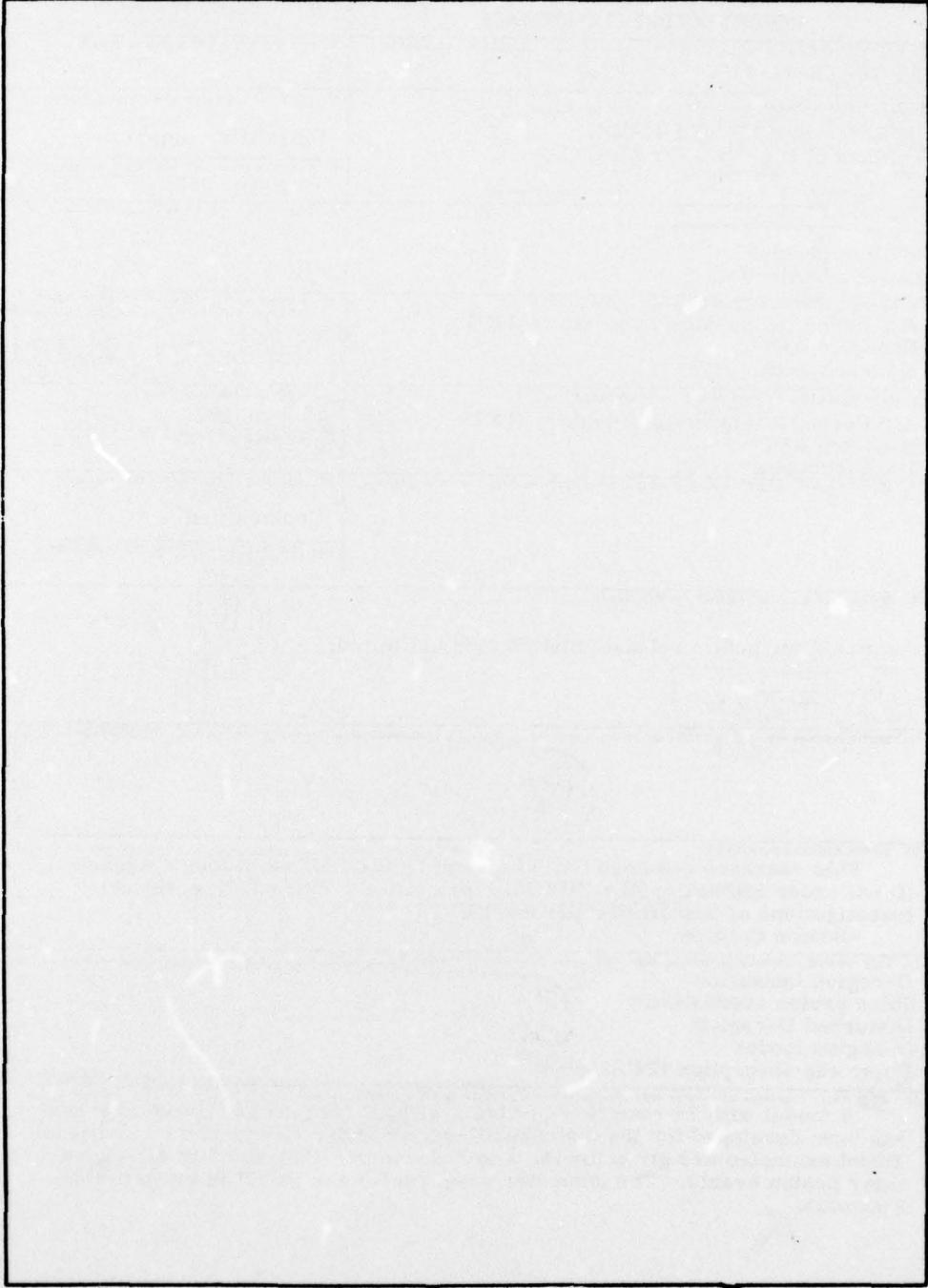
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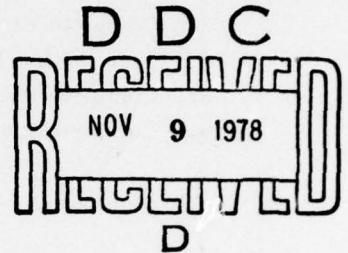
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## Steady-State Multi-Ion Disturbed D-Region Model

### I. INTRODUCTION

Previously<sup>1</sup> we described a model for the nighttime disturbed D-region which treated negative ions in a highly simplified manner. Good agreement was attained<sup>2</sup> between the model and the nighttime observations of 3 November 1969 at Ft. Churchill, Canada, during a solar proton event (SPE). More recently, by incorporating the latest negative ion chemistry, exclusive of hydration processes, we have found<sup>3</sup> that good agreement can be obtained between our latest model and the three daytime observations of 2, 3, and 4 November 1969 for this same event and location. In this report we document the new program which includes not only a more satisfactory treatment of negative ions, but also includes some new positive ion chemistry involving  $\text{NO}^+$  ions. We also provide here the numerical results obtained in applying this program to the solar proton events of 2 to 5 November 1969 and 3 to 11 August 1972.

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(Received for publication 14 June 1978)

1. Swider, W., and Foley, C.I. (1975) Computer Program for the Disturbed Steady-State Nighttime D-region, AFCRL-TR-75-0150.
2. Swider, W., and Narcisi, R.S. (1975) A study of the nighttime D-region during a PCA event, *J. Geophys. Res.* 80:655-664.
3. Swider, W., Keneshea, T.J., and Foley, C.I. (1978) An SPE-disturbed D-region model, *Planet. Space Sci.* 26:

## 2. OUTLINE OF MODEL

The computer program is reproduced in Appendix A. All photorates in this code are multiplied by DD which is set to 1 for daytime and 0 for nighttime.

The iterative scheme developed to solve for all species concentrations is similar to that derived before.<sup>1</sup> The present scheme is more complex; two initial concentrations are now needed, one for electrons and one for the positive ion sum. Using the initial concentrations for electrons [e], and the positive ion sum, SP, the individual negative ions are determined and then summed, the sum denoted by NSUM. Then the positive ions are individually calculated and summed, PSUM. A new  $[e] = \{ \text{previous } [e] + \text{PSUM}/(1+\lambda) \}/2$ , where  $\lambda = \text{NSUM}/\text{previous } [e]$ , and a new  $SP = \{ \text{previous } [e] + \text{NSUM} + \text{PSUM} \}/2$  are then determined. This sequence is repeated until PSUM agrees with NSUM+[e] to some desired precision, usually  $\pm 1$  percent. In the examples to be shown later, not more than 9 iterations were required at any particular altitude (40-90 km) in order to attain this criterion.

Initial daytime electron concentrations were obtained from

$$[e] = (q/SI)^{1/2} \quad (1) \text{ L 189}$$

where  $SI = \psi$  represents values for the effective electron loss coefficient as determined<sup>4</sup> for the 2 to 5 November 1969 SPE. The number following the equation number in the text, as L 189 above, means that Eq. (1) is or begins on line 189 of the program. Initial nighttime electron concentrations were estimated, as before,<sup>1</sup> from the equation<sup>5</sup>

$$[e] = \left\{ (L(A)/2\alpha_D)^2 + q/\alpha_D \right\}^{1/2} - L(A)/2\alpha_D \quad (2) \text{ L 191}$$

where  $\alpha_D$  is the mean dissociative recombination coefficient and

$$L(A) = k_{61}[O_2]^2 + k_{62}[O_2][N_2] \quad (3) \text{ L 187}$$

is the loss rate ( $\text{sec}^{-1}$ ) of electrons by attachment to  $O_2$  with  $O_2$  and  $N_2$  as third bodies. The reaction rates and rate coefficients are listed later, the subscripts for  $k$  referring to the processes are as numbered in that listing

4. Swider, W., and Dean, W.A. (1975) Effective electron loss coefficient of the disturbed daytime D-region, *J. Geophys. Res.* 80:1815-1819.
5. Swider, W., Narcisi, R.S., Keneshea, T.J., and Ulwick, J.C. (1971) Electron loss during a nighttime PCA event, *J. Geophys. Res.* 76:4691-4694.

Initial total positive ion concentrations were determined from the expression

$$SP = \left\{ q \left( \frac{5[O]}{\alpha_D} + \frac{[O_3]}{\alpha_i} \right) / (5[O] + [O_3]) \right\}^{1/2} \quad (4) \text{ L193}$$

where  $\alpha_i$  is the mean ion-ion recombination coefficient. The multiplicative factor for  $[O]$ , somewhat arbitrary, was selected after some trial runs as a factor for improving SP vis-a-vis the final calculated positive ion sum. Equation (4) simplifies to the familiar expressions  $(q/\alpha_D)^{1/2}$  at high D-region altitudes where  $[O] \gg [O_3]$  and  $(q/\alpha_i)^{1/2}$  at low D-region altitudes where  $([O_3] \gg [O])$ . Values chosen for  $\alpha_D$  and  $\alpha_i$  were  $4 \times 10^{-7} \text{ cm}^3/\text{sec}$  (L 73) and  $6 \times 10^{-8} \text{ cm}^3/\text{sec}$  (L 74) respectively. The former value was selected as that typical for a mixture of  $\text{NO}^+$  and  $\text{O}_2^+$  ions at D-region temperatures, whereas the latter value is based upon laboratory measurements by Smith et al.<sup>6</sup> The fact that all ion-ion recombination coefficients were set at  $6 \times 10^{-8} \text{ cm}^3/\text{sec}$  in this program is in accord with the laboratory work. However, this constraint is not a necessary one in the operation of this program; one  $\alpha_i$  being required only for initial SP.

The positive ion equations are similar to those listed before except that changes have been made because of our inclusion of photodissociation processes for  $\text{O}_4^+$  and  $\text{O}_2^+$  ( $\text{H}_2\text{O}$ ) ions and by our addition of the ions  $\text{NO}^+$  ( $\text{N}_2$ ),  $\text{NO}^+$  ( $\text{H}_2\text{O}$ ) ( $\text{N}_2$ ),  $\text{NO}^+$  ( $\text{H}_2\text{O}$ ) ( $\text{CO}_2$ ),  $\text{NO}^+$  ( $2\text{H}_2\text{O}$ ) ( $\text{N}_2$ ) and  $\text{NO}^+$  ( $2\text{H}_2\text{O}$ ) ( $\text{CO}_2$ ). The list of positive ion reactions, numbered 4 through 52 in Table 1 for the 21 positive ions considered, is fairly complete. Rate coefficients are generally from the same sources already identified.<sup>2,3</sup> Rates for photodissociation processes 4 and 5 in Table 1 are from Vanderhoff and Niles,<sup>7</sup> while the rate coefficient  $k_{43}$  was taken from the work of Johnsen et al.<sup>8</sup> Rate coefficients for reactions 45 and 48 were set equal to that for  $k_{43}$ . The rate coefficient  $k_{51}$  is based<sup>9</sup> upon parameters measured by Johnsen et al.<sup>8</sup> High rate coefficients for processes 44, 46, 47, 49 and 50 were chosen in accordance with the fact that they are all "switching" reactions. Computation of the individual positive ions begins with  $\text{O}_2^+$  (PION 4, J), line 204 of the program and is completed by line 257 with PION (24, J) =  $\text{H}_9\text{O}_4^+$ . Thus, this rather extensive list of positive ions (21) requires only 53 lines in the computer program.

6. Smith, D., Adams, N.G., and Church, M.J. (1976) Mutual neutralization rates of ionospherically important ions, Planet. Space Sci. 24:697-703.
7. Vanderhoff, J.A., and Niles, F.E. (1976) Recent development in measurements of photodissociation for atmospheric positive ions, EOS, 57:303.
8. Johnsen, R., Huang, C.-M., and Biondi, M.A. (1975) The formation and breakup of  $\text{NO}^+$   $\text{N}_2$  clusters in  $\text{N}_2$  at low temperatures, J. Chem Phys. 63:3374-3378.
9. Heimerl, J.M. (1976) Values for Selected Collisional Dissociation Rate Coefficients of Positive Clustered Ions, BRL-IMR-499.

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Table 1. Positive Ion Reactions. Units for photo-processes, two-body and three-body processes are  $\text{sec}^{-1}$ ,  $\text{cm}^3/\text{sec}$  and  $\text{cm}^6/\text{sec}$ , respectively. The various process coefficients,  $\kappa = A(T/300)^B eD/T$ , are presented in the format A B D

				A	B	D
4	$\text{O}4^+$	$\rightarrow \text{HV}$	$= \text{O}2^+$	$\rightarrow \text{O}2$	$3.00\text{E-}01$	
5	$\text{O}2^+\text{.H}_2\text{O}$	$\rightarrow \text{HV}$	$= \text{O}2^+$	$\rightarrow \text{H}_2\text{O}$	$6.00\text{E-}01$	
6	$\text{O}2^+$	$\rightarrow \text{NO}$	$= \text{NO}^+$	$\rightarrow \text{O}2$	$4.50\text{E-}10$	
7	$\text{O}2^+$	$\rightarrow \text{O}2 + \text{O}2$	$= \text{O}4^+$	$\rightarrow \text{O}2$	$3.30\text{E-}30$	$-3.2$
8	$\text{O}4^+$	$\rightarrow \text{O}$	$= \text{O}2^+$	$\rightarrow \text{O}3$	$3.00\text{E-}10$	
9	$\text{O}4^+$	$\rightarrow \text{H}_2\text{O}$	$= \text{O}2\text{+H}_2\text{O}$	$\rightarrow \text{O}2$	$1.50\text{E-}09$	
10	$\text{O}2^+\text{H}_2\text{O}$	$\rightarrow \text{H}_2\text{O}$	$= \text{H}_3\text{O+DH}$	$\rightarrow \text{O}2$	$1.00\text{E-}09$	
11	$\text{O}2^+\text{H}_2\text{O}$	$\rightarrow \text{H}_2\text{O}$	$= \text{H}_3\text{O}^+$	$\rightarrow \text{OH} + \text{O}2$	$2.00\text{E-}10$	
12	$\text{H}_3\text{O+OH}$	$\rightarrow \text{H}_2\text{O}$	$= \text{H}_5\text{O}2^+$	$\rightarrow \text{OH}$	$1.40\text{E-}09$	
13	$\text{H}_3\text{O}^+$	$\rightarrow \text{N}_2 + \text{N}_2$	$= \text{H}_3\text{O+}\text{N}_2$	$\rightarrow \text{N}_2$	$1.40\text{E-}30$	$-2.0$
14	$\text{H}_3\text{O+}\text{N}_2$	$\rightarrow \text{CO}_2$	$= \text{H}_3\text{O+}\text{CO}_2$	$\rightarrow \text{N}_2$	$1.00\text{E-}09$	
15	$\text{H}_3\text{O+}\text{CO}_2$	$\rightarrow \text{H}_2\text{O}$	$= \text{H}_5\text{O}2^+$	$\rightarrow \text{CO}_2$	$1.00\text{E-}10$	
16	$\text{H}_5\text{O}2^+$	$\rightarrow \text{CO}_2 + \text{M}$	$= \text{H}_5\text{O}2^+\text{.CO}_2 + \text{M}$		$3.00\text{E-}30$	
17	$\text{H}_5\text{O}2^+\text{.CO}_2 + \text{H}_2\text{O}$		$= \text{H}_7\text{O}3^+ + \text{CO}_2$		$1.00\text{E-}10$	
18	$\text{H}_3\text{O}^+$	$\rightarrow \text{H}_2\text{O} + \text{N}$	$= \text{H}_5\text{O}2^+$	$\rightarrow \text{M}$	$3.50\text{E-}27$	$-3.0$
19	$\text{H}_5\text{O}2^+$	$\rightarrow \text{H}_2\text{O} + \text{M}$	$= \text{H}_7\text{O}3^+$	$\rightarrow \text{M}$	$2.20\text{E-}27$	$-3.0$
20	$\text{H}_7\text{O}3^+$	$\rightarrow \text{H}_2\text{O} + \text{M}$	$= \text{H}_9\text{O}4^+$	$\rightarrow \text{M}$	$2.30\text{E-}27$	$-3.0$
21	$\text{NO}^+$	$\rightarrow \text{CO}_2 + \text{N}_2$	$= \text{NO+CO}_2$	$\rightarrow \text{N}_2$	$3.00\text{E-}29$	$-2.0$
22	$\text{NO+CO}_2$	$\rightarrow \text{H}_2\text{O}$	$= \text{NO+H}_2\text{O}$	$\rightarrow \text{CO}_2$	$5.00\text{E-}10$	
23	$\text{NO+H}_2\text{O}$	$\rightarrow \text{H}_2\text{O} + \text{N}_2$	$= \text{NO+}(\text{H}_2\text{O})2^+ + \text{N}_2$		$1.10\text{E-}27$	$-4.7$
24	$\text{NO+}(\text{H}_2\text{O})2^+ + \text{H}_2\text{O} + \text{N}_2$		$= \text{NO+}(\text{H}_2\text{O})3^+ + \text{N}_2$		$1.60\text{E-}27$	$-4.7$
25	$\text{NO+}(\text{H}_2\text{O})3^+ + \text{H}_2\text{O}$		$= \text{H}_7\text{O}3^+ + \text{HN}_2\text{O}$		$7.00\text{E-}11$	
26	$\text{NO}^+$	$\rightarrow \text{E}$	$= \text{N}$	$\rightarrow \text{O}$	$4.00\text{E-}07$	$-1.0$
27	$\text{O}2^+$	$\rightarrow \text{E}$	$= \text{O}$	$\rightarrow \text{O}$	$2.00\text{E-}07$	$-1.0$
28	$\text{O}4^+$	$\rightarrow \text{E}$	$= \text{O}2$	$\rightarrow \text{O}2$	$2.00\text{E-}06$	
29	$\text{O}2^+\text{.H}_2\text{O}$	$\rightarrow \text{E}$	$= \text{O}2$	$\rightarrow \text{H}_2\text{O}$	$2.00\text{E-}06$	
30	$\text{H}_3\text{O+}\text{.OH}$	$\rightarrow \text{E}$	$= 2\text{H}_2\text{O}$		$2.00\text{E-}06$	
31	$\text{H}_3\text{O}^+$	$\rightarrow \text{E}$	$= \text{H}_2$	$\rightarrow \text{OH}$	$1.00\text{E-}05$	
32	$\text{H}_5\text{O}2^+$	$\rightarrow \text{E}$	$= \text{H}_2\text{O}$	$\rightarrow \text{H}_2 + \text{OH}$	$2.00\text{E-}05$	
33	$\text{H}_7\text{O}3^+$	$\rightarrow \text{E}$	$= 2\text{H}_2\text{O}$	$\rightarrow \text{H}_2 + \text{OH}$	$4.00\text{E-}06$	
34	$\text{H}_9\text{O}4^+$	$\rightarrow \text{E}$	$= 3\text{H}_2\text{O}$	$\rightarrow \text{H}_2 + \text{OH}$	$5.00\text{E-}06$	
35	$\text{H}_3\text{O+}\text{N}_2$	$\rightarrow \text{E}$	$= \text{H}$	$\rightarrow \text{H}_2\text{O} + \text{N}_2$	$2.00\text{E-}05$	
36	$\text{H}_3\text{O+}\text{CO}_2$	$\rightarrow \text{E}$	$= \text{H}$	$\rightarrow \text{H}_2\text{O} + \text{CO}_2$	$2.00\text{E-}05$	
37	$\text{H}_5\text{O}2^+\text{.CO}_2 + \text{E}$		$= \text{H}$	$\rightarrow 2\text{H}_2\text{O+CO}_2$	$3.20\text{E-}05$	
38	$\text{NO+CO}_2$	$\rightarrow \text{E}$	$= \text{NO}$	$\rightarrow \text{CO}_2$	$1.50\text{E-}05$	
39	$\text{NO+H}_2\text{O}$	$\rightarrow \text{E}$	$= \text{NO}$	$\rightarrow \text{H}_2\text{O}$	$1.50\text{E-}05$	
40	$\text{NO+}(\text{H}_2\text{O})2^+ + \text{E}$		$= \text{NO}$	$\rightarrow 2\text{H}_2\text{O}$	$3.00\text{E-}05$	
41	$\text{NO+}(\text{H}_2\text{O})3^+ + \text{E}$		$= \text{NO}$	$\rightarrow 3\text{H}_2\text{O}$	$4.50\text{E-}05$	
42	$\text{O}4^+$	$\rightarrow \text{M}$	$= \text{O}2^+$	$\rightarrow \text{O}2 + \text{M}$	$3.30\text{E-}06$	$-4.0 - 5.0 \text{E}+03$
43	$\text{NO}^+$	$\rightarrow \text{N}_2 + \text{N}_2$	$= \text{NO+}\text{N}_2$	$\rightarrow \text{N}_2$	$2.00\text{E-}31$	$-4.4$
44	$\text{NO+}\text{N}_2$	$\rightarrow \text{CO}_2$	$= \text{NO+CO}_2$	$\rightarrow \text{N}_2$	$2.00\text{E-}09$	$0.0$
45	$\text{NO+}\text{H}_2\text{O}$	$\rightarrow \text{N}_2 + \text{N}_2$	$= \text{NO+H}_2\text{O}\text{N}_2$	$\rightarrow \text{N}_2$	$2.00\text{E-}31$	$-4.4$
46	$\text{NO+H}_2\text{O}\text{N}_2$	$\rightarrow \text{CO}_2$	$= \text{NO+H}_2\text{O}\text{CO}_2$	$\rightarrow \text{N}_2$	$2.00\text{E-}09$	$0.0$
47	$\text{NO+H}_2\text{O}\text{CO}_2 + \text{H}_2\text{O}$		$= \text{NO+}\text{H}_2\text{O} + \text{CO}_2$		$2.00\text{E-}09$	$0.0$
48	$\text{NO+}\text{H}_2\text{O} + \text{N}_2 + \text{N}_2$		$= \text{NO+H}_2\text{O}\text{N}_2 + \text{N}_2$		$2.00\text{E-}31$	$-4.4$
49	$\text{NO+H}_2\text{O}\text{N}_2 + \text{CO}_2$		$= \text{NO+H}_2\text{O}\text{CO}_2 + \text{N}_2$		$2.00\text{E-}09$	$0.0$
50	$\text{NO+H}_2\text{O}\text{CO}_2 + \text{H}_2\text{O}$		$= \text{NO+}\text{H}_2\text{O} + \text{CO}_2$		$2.00\text{E-}09$	$0.0$
51	$\text{NO+}\text{N}_2$	$\rightarrow \text{N}_2$	$= \text{NO}^+$	$\rightarrow \text{N}_2 + \text{N}_2$	$1.00\text{E-}08$	$-4.4 - 2.10\text{E}+03$
52	$\text{H}_9\text{O}4^+$	$\rightarrow \text{M}$	$= \text{H}_7\text{O}3^+$	$\rightarrow \text{H}_2\text{O} + \text{M}$	$1.20\text{E-}01$	$-4.0 - 8.80\text{E}+03$

Eight negative ions are included in this program,  $O_2^-$ ,  $O_4^-$ ,  $CO_4^-$ ,  $CO_3^-$ ,  $O^-$ ,  $O_3^-$ ,  $NO_2^-$  and  $NO_3^-$ . This is also the order in which the respective ion concentrations are solved. Considerable algebraic manipulation was required for these solutions which will not be described in the text but can be followed in the subroutine NEGION, lines 25-87. The ion concentrations of several ions are easily solved, but the main trick was to eliminate  $CO_3^-$  from the equation for  $O_2^-$  which was accomplished by reducing  $CO_3^-$  to a function of  $O_2^-$ . Thus, the solution of  $CO_3^-$  (line 64) is expressed simply as  $S[O_2^-]/R$ , but S, lines 35-39 and R, line 34, are quite complex terms involving the lengthy algebraic factors T, W, V, U, which are described on lines 29-32. The negative ion processes used in the calculations are given in Table 2. Rate coefficients for non-proton processes were taken mainly from the work of the Boulder group (for example, Ferguson)<sup>10</sup> including a recent update<sup>11</sup> for  $k_{80} + k_{81}$ ,  $8.8 \times 10^{-10} \text{ cm}^3/\text{sec}$  with product branches which we took as equal. Photodissociation/photodetachment rates are generally those listed by Peterson et al<sup>12</sup> or estimated by Niles<sup>13</sup> ( $NO_x^-$ ).

Profiles of neutrals O,  $O_2$ ,  $O_3$ ,  $O_2(\Delta)$ ,  $N_2$ ,  $CO_2$ ,  $H_2O$ , NO and  $NO_2$  plus temperature were required inputs to the computations. Total concentrations, [M], and temperatures T, were taken from CIRA\* 1972 for the appropriate month and latitude with  $N_2 = 0.7808$  [M],  $O_2 = 0.2095$  [M] and  $CO_2 = 3 \times 10^{-2}$  [M]. Water vapor concentrations,  $[H_2O]$  were set at  $10^{-6}$  [M]. The choices for the other minor neutrals are described elsewhere.<sup>3</sup> Each output gives a complete account of all the neutral concentrations utilized. The daytime and nighttime minor neutral concentrations used in the computations will be presented in typical printouts for daytime and nighttime situations.

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10. Ferguson, E. E. (1975) in Atmospheres of Earth and the Planets (Ed. B. M. McCormac) Reidel, Dordrecht, Holland, pp 197-210.
11. Ferguson, E. E. (1977) Paper presented at IAGA meeting in Seattle, Washington,
12. Peterson, J. R., Cosby, P. C., and Moseley, J. T. (1977) Photo-destruction of atmospheric negative and positive ions, Space Res. 17:243-246.
13. Niles, F. E. (1976) private communication.

\* COSPAR International Reference Atmosphere.

Table 2. Negative Ion Reactions. Units and format are as for Table 1

				A	B	D
60	O2-	+ O3	= O3-	+ O2	5.00E-10	
51	O2	+ E	+ O2	= O2-	1.40E-29	-1.0-6.00E+02
62	O2	+ E	+ N2	= O2-	+ N2	1.00E-31
63	O2-	+ O	= O3	+ E	1.50E-10	
64	O2-	+ O	= O-	+ O2	1.50E-10	
65	O2-	+ O2(10)	= O2	+ O2	+ E	2.00E-10
66	O2-	+ O2	+ O2	= O4-	+ O2	3.50E-31 -1.0
67	O4-	+ CO2	= CO4-	+ O2	4.30E-10	
68	CO4-	+ O3	= O3-	+ CO2	+ O2	1.30E-10
69	CO4-	+ NO	= NO3-	+ CO2		4.80E-11
70	CO4-	+ O	= CO3-	+ O2		1.50E-10
71	O3-	+ O	= O2-	+ O2		3.20E-10
72	O3-	+ CO2	= CO3-	+ O2		5.50E-10
73	CO3-	+ O	= O2-	+ CO2		1.10E-10
74	CO3-	+ NO	= NO2-	+ CO2		1.10E-11
75	CO3-	+ NO2	= NO3-	+ CO2		2.00E-10
76	NO2-	+ O3	= NO3-	+ O2		9.00E-11
77	O-	+ O2	+ O2	= O3-	+ O2	1.10E-30 -1.0
78	O-	+ O	= O2	+ E		2.00E-10
79	O-	+ O2(10)	= O3	+ E		3.00E-10
80	O-	+ O3	= O3-	+ O		4.40E-10
81	O-	+ O3	= O2-	+ O2		4.40E-10
91	O2-	+ HV	= O2	+ E		6.50E-01
92	O-	+ HV	= O	+ E		2.80E+00
93	CO4-	+ HV	= CO2	+ O2	+ E	6.00E-01
94	CO3-	+ HV	= CO2	+ O-		4.00E-01
95	NO2-	+ HV	= NO2	+ E		6.00E-02
96	NO3-	+ HV	= NO2-	+ O		6.00E-02
97	NO3-	+ HV	= NO	+ O2	+ E	4.40E-03

### 3. NUMERICAL EXAMPLE: 2 November 1969 SPE

Table 3 is a typical printout. It was generated specifically for the ionization production rate associated with the daytime electron SPE concentrations measured<sup>14</sup> on 2 November 1969, Flight B4 at Ft. Churchill, Canada. Photodetachment/photodissociation rates  $k_{91} - k_{97}$  have been doubled to improve the agreement between the data and the computations. The agreement is quite good, as seen in Figure 1. The results obtained with the "normal" Table 2 values for  $k_{91} - k_{97}$  are discussed elsewhere<sup>3</sup> in conjunction with the doubled rates. The rate coefficient  $k_{43}$  has been set to 0 in this example because  $\text{NO}^+$  otherwise seemed to fall off faster with decreasing altitude than the data for this event admit.<sup>15</sup> This  $\text{NO}^+$  behavior is shown in Figure 2 which is a plot of the principal positive ions listed in Table 3.

14. Dean, W. A. (1972) in Proc. COSPAR Symp. on SPE of Nov. 1969, AFCRL-72-0474, pp 291-306.

15. Narcisi, R. S., Philbrick, C. R., Thomas, D. M., Bailey, A. D., Wlodyka, L. E., Baker, D., Federico, G., Wlodyka, R., and Gardner, M. E. (1972) in Proc. COSPAR Symp. on SPE of Nov. 1969, AFCRL-72-0474, pp 421-432.

Also shown in Figure 2 is an  $\text{NO}^+$  profile obtained with  $k_{43} \neq 0$ , specifically, the value given in Table 1. The output associated with  $k_{43} \neq 0$  is given in Table 4 minus the first part of the output which is the same as that for Table 3. The electron concentrations are somewhat higher for the first case, the greatest difference being near 78-80 km. This is because with  $k_{43} \neq 0$ ,  $\text{O}_2^+/\text{NO}^+$  is higher at 80 km and  $\text{O}_2^+$  has a lower dissociative recombination coefficient, twice that of  $\text{NO}^+$  (as adopted here, Table 1). In other words, for the same ionization production rate the electron concentration will be a factor  $(2)^{1/2}$  greater if only  $\text{O}_2^+$  ions are present as compared to solely  $\text{NO}^+$  ions. Slightly lower electron concentrations are encountered near 75 km for the  $k_{43} \neq 0$  case because conversion of  $\text{NO}^+$  to oxonium ions leads to slightly higher electron loss since the latter ions have greater dissociative recombination coefficients than  $\text{NO}^+$  (Table 1). Below 75 km, there is virtually no difference in [e] for the two cases, because  $\text{NO}^+$  contributes very little to the ion chemistry in either case. In fact, since  $\text{O}_2^+$  is the precursor ion for the SPE situation, the choice of  $k_{43}$  is rather moot. Furthermore, inclusion of collisional breakup expressions for ions like  $\text{NO}^+ (\text{N}_2)(\text{CO}_2)$ , would probably increase the  $\text{NO}^+$  concentrations for the  $k_{43} \neq 0$  case and further cloud the issue as to the role of  $\text{NO}^+$  clustering in the D-region under SPE conditions. Another important factor not to be forgotten in regards to the  $\text{NO}^+$  distribution is the fact that it depends strongly on the NO profile chosen. The NO profile selected is based in part upon its compatibility with the data<sup>2</sup> and is probably the strongest reason why our results should not be construed as giving a major clue as to the role of  $\text{NO}^+$  clusters in the D-region.

Vanderhoff and Niles report<sup>7</sup> that the photodissociation of oxonium is negligible considering the small cross-sections for the process. On the other hand, photodissociation cross-sections for  $\text{O}_4^+$ ,  $\text{O}_2^+(\text{H}_2\text{O})$ , and  $\text{O}_2^+(\text{CO}_2)$  are large.<sup>16</sup> We have included the recommended photodissociation rates for the first two species; processes 4 and 5 in Table 1. The inclusion of these rates had the effect of lowering the crossover point between the simple ions ( $\text{NO}^+$ ,  $\text{O}_2^+$ ) and the oxonium ions by about 2 km. Thus, the effect is not a major one. A negligible further change in crossover point altitude was found when these rates were doubled to account roughly for scattered and reflected light as has been done for the rates  $k_{91} - k_{97}$ . Photodissociation of  $\text{O}_2^+(\text{CO}_2)$  is not significant in the D-region because this species is not produced effectively at these altitudes.

16. Moseley, J. T., Cosby, P. C., and Peterson, J. R. (1977) Laboratory measurements of photodissociation and photodetachment cross-sections of atmospheric ions, EOS 58:698.

Although the daytime electron concentrations for 3 and 4 November 1969, besides the 2 November 1969 case shown here agree satisfactorily with the data,<sup>3</sup> it should not be assumed that the negative ion problem is settled. The hydration of negative ions has been ignored (Figure 3), and this is undoubtedly unrealistic. The agreement noted therefore, only implies that the negative ion chemistry is satisfactory in regards to the electron distribution in daytime. Thus, negative ions like  $\text{NO}_2^-$  and  $\text{NO}_3^-$  that appear to have negligible photodetachment rates, may be hydrated to an important extent but have no impact upon the electron chemistry because electrons are presumably even less readily detached from  $\text{NO}_x^-$  hydrates. Formation of  $\text{CO}_3^- (\text{H}_2\text{O})$  has been shown<sup>3</sup> to be unimportant in the daytime because the photodestruction rate is large. Even sunset does not appear to be influenced<sup>3</sup> by the omission of hydration processes, but sunrise is another matter. The major reason for a poor match<sup>3</sup> of the November 1969 SPE sunrise data with time-dependent calculations using the same chemistry as here is quite likely due to the considerable hydration of negative ions that occurs unhindered by photodissociation processes at night.

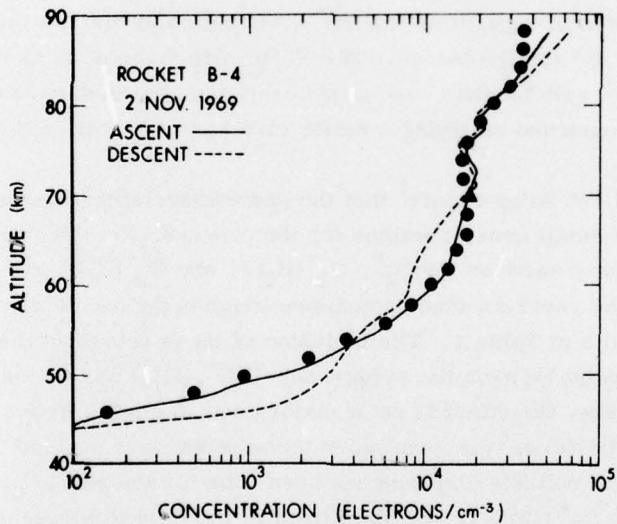


Figure 1. Measured and Computed Electron Concentrations for Rocket B-4 Launched at 2110 UT, 2 November 1969. The solar zenith angle was  $83.2^\circ$ . The computed electron concentrations are from Table 4

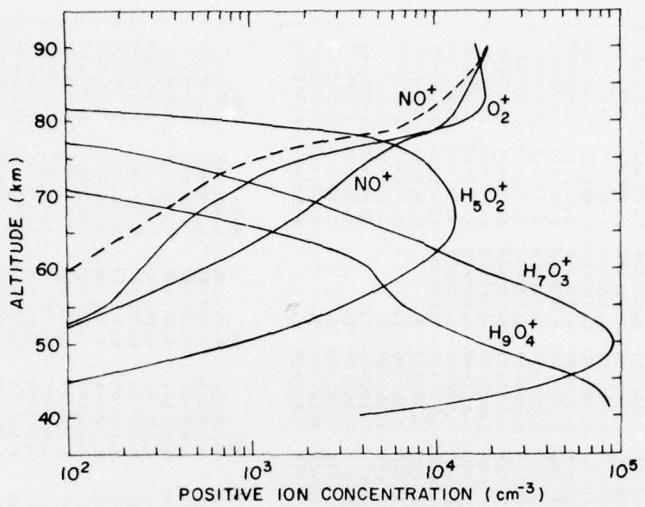


Figure 2. Principal Positive Ions Computed (Table 3) for Rocket B-4. Dashed curve from Table 4

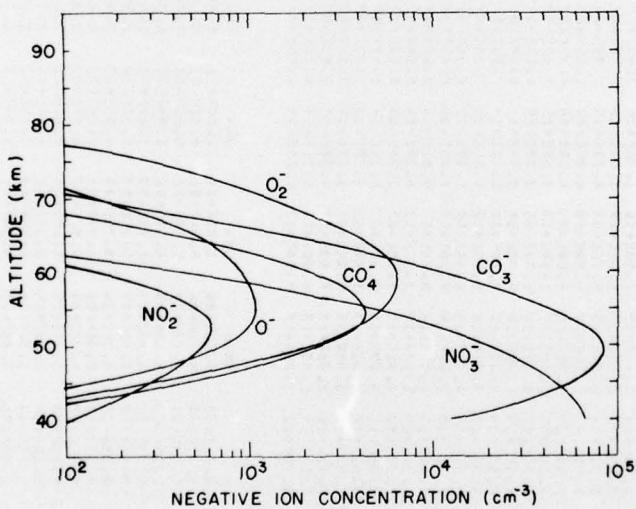


Figure 3. Principal Negative Ions Computed (Table 3) for Rocket B-4

Table 3. Complete Printout of Calculations for 2110 UT, 2 November 1969. The first three sets of altitude listings give temperature (°K) and assumed (neutral) and calculated electron and ion concentrations in units of  $\text{cm}^{-3}$ . The last set of altitude listings shows parameters described in Section 2, Outline of Model such as  $L(A)$ , Eq. (2) of text,  $\lambda$ , and  $Q/[e]_2^2$ , where  $Q$  is the ionization production rate,  $\text{cm}^{-3} \text{ sec}^{-1}$ . ( $k_{43}$  set to zero)

ALTITUDE	0			0.2			0.3			H2			CO2			H2O			NO2			N			TEMP					
	0	0.2	0.3	0	0.2	0.3	0	0.2	0.3	0	0.2	0.3	0	0.2	0.3	0	0.2	0.3	0	0.2	0.3	0	0.2	0.3	0	0.2	0.3			
40.	1.06E+09	1.60E+16	4.30E+11	5.96E+16	1.00E+09	2.29E+13	7.63E+10	7.63E+16	7.63E+16	1.06E+09	2.29E+13	7.63E+10	1.06E+10	2.29E+13	7.63E+10	1.06E+09	2.29E+13	7.63E+10												
62.	1.49E+09	1.17E+16	2.50E+11	4.37E+16	1.00E+09	2.29E+13	5.38E+13	5.38E+16	5.38E+16	1.00E+09	2.29E+13	5.38E+13	1.00E+10	2.29E+13	5.38E+13	1.00E+09	2.29E+13	5.38E+13												
44.	1.80E+09	8.80E+15	6.15E+11	5.00E+16	5.00E+08	4.50E+10	4.26E+10	4.26E+16	4.26E+16	5.00E+08	4.50E+10	4.26E+10	1.26E+10	5.00E+08	4.50E+10	4.26E+10														
66.	2.20E+09	6.49E+15	8.00E+10	4.40E+16	4.40E+08	4.40E+10	3.42E+12	3.42E+16	3.42E+16	4.40E+08	4.40E+10	3.42E+12	1.94E+10	4.40E+08	4.40E+10	3.42E+12														
48.	2.51E+09	6.22E+15	5.00E+10	1.00E+16	1.00E+08	1.00E+15	1.20E+08	1.20E+16	1.20E+16	1.00E+08	1.00E+15	1.20E+08	2.40E+10	1.00E+08	1.00E+15	1.20E+08	1.00E+08													
50.	2.90E+09	3.71E+15	1.00E+09	1.00E+16	1.00E+08	1.00E+15	1.00E+08	1.00E+16	1.00E+16	1.00E+08	1.00E+15	1.00E+08	1.77E+10	1.00E+08	1.00E+15	1.00E+08	1.00E+08													
52.	3.10E+09	2.83E+15	1.50E+10	1.05E+16	1.05E+08	1.05E+15	1.70E+08	1.70E+16	1.70E+16	1.05E+08	1.05E+15	1.70E+08	1.35E+10	1.05E+08	1.05E+15	1.70E+08	1.05E+08													
54.	3.30E+09	2.20E+15	8.70E+09	6.70E+16	6.70E+09	6.70E+15	1.30E+08	1.30E+16	1.30E+16	6.70E+09	6.70E+15	1.30E+08	1.05E+10	6.70E+09	6.70E+15	1.30E+08	6.70E+09	6.70E+15												
56.	3.50E+09	1.56E+15	5.00E+09	5.00E+16	5.00E+09	5.00E+15	1.00E+07	1.00E+16	1.00E+16	5.00E+09	5.00E+15	1.00E+07	7.50E+08	5.00E+09	5.00E+15	1.00E+07	5.00E+09	5.00E+15												
58.	3.60E+09	1.34E+15	2.00E+09	2.00E+16	2.00E+09	2.00E+15	3.00E+07	3.00E+16	3.00E+16	2.00E+09	2.00E+15	3.00E+07	4.90E+12	2.00E+09	2.00E+15	3.00E+07	2.00E+09	2.00E+15												
60.	3.60E+09	1.04E+15	1.60E+09	1.60E+16	1.60E+09	1.60E+15	5.70E+07	5.70E+16	5.70E+16	1.60E+09	1.60E+15	5.70E+07	8.77E+09	1.60E+09	1.60E+15	5.70E+07	1.60E+09	1.60E+15												
62.	3.60E+09	6.29E+14	6.17E+14	9.00E+08	9.00E+08	9.00E+08	3.05E+15	3.05E+15	3.05E+15	9.00E+08	9.00E+08	9.00E+08	1.17E+12	9.00E+08	9.00E+08	3.05E+15	9.00E+08	9.00E+08												
56.	3.50E+09	6.29E+14	6.17E+14	9.00E+08	9.00E+08	9.00E+08	2.34E+15	2.34E+15	2.34E+15	9.00E+08	9.00E+08	9.00E+08	1.17E+12	9.00E+08	9.00E+08	2.34E+15	9.00E+08	9.00E+08												
58.	3.50E+09	3.30E+14	3.28E+14	2.00E+08	2.00E+08	2.00E+08	1.75E+15	1.75E+15	1.75E+15	2.00E+08	2.00E+08	2.00E+08	1.37E+15	2.00E+08	2.00E+08	1.75E+15	2.00E+08	2.00E+08												
64.	3.00E+09	2.76E+14	2.07E+14	7.00E+07	7.00E+07	7.00E+07	2.70E+07	2.70E+07	2.70E+07	7.00E+07	7.00E+07	7.00E+07	2.97E+11	7.00E+07	7.00E+07	2.70E+07	7.00E+07	7.00E+07												
72.	3.00E+09	2.07E+14	2.07E+14	7.00E+07	7.00E+07	7.00E+07	2.70E+07	2.70E+07	2.70E+07	7.00E+07	7.00E+07	7.00E+07	2.97E+11	7.00E+07	7.00E+07	2.70E+07	7.00E+07	7.00E+07												
76.	3.40E+09	1.57E+14	1.57E+14	3.50E+08	3.50E+08	3.50E+08	2.50E+07	2.50E+07	2.50E+07	3.50E+08	3.50E+08	3.50E+08	2.50E+11	3.50E+08	3.50E+08	2.50E+07	3.50E+08	3.50E+08												
78.	4.50E+09	1.17E+14	3.35E+08																											
80.	9.00E+09	8.80E+13	2.90E+13	2.00E+08	2.00E+08	2.00E+08	2.00E+07	2.00E+07	2.00E+07	3.28E+16	3.28E+16	3.28E+16	2.00E+16	3.28E+16	3.28E+16	2.00E+07	3.28E+16	3.28E+16												
86.	2.20E+11	2.51E+13	7.00E+13	7.00E+07	7.00E+07	7.00E+07	5.50E+07	5.50E+07	5.50E+07	3.77E+13	3.77E+13	3.77E+13	4.00E+10	3.77E+13	3.77E+13	5.50E+07	3.77E+13	3.77E+13												
90.	2.70E+11	1.80E+13	1.80E+13	7.00E+07	7.00E+07	7.00E+07	6.1E+07	6.1E+07	6.1E+07	4.00E+13	4.00E+13	4.00E+13	4.00E+10	4.00E+13	4.00E+13	6.1E+07	4.00E+13	4.00E+13												
96.	3.20E+11	1.28E+13	7.00E+07	7.00E+07	7.00E+07	7.00E+07	4.00E+07	4.00E+07	4.00E+07	3.77E+13	3.77E+13	3.77E+13	4.00E+10	3.77E+13	3.77E+13	4.00E+07	3.77E+13	3.77E+13												
98.	3.55E+04	1.59E+01	9.24E+02																											

Table 3. Complete Printout of Calculations for 2110 UT, 2 November 1969 (Cont.)

ALTITUDE	NO+H2O		NO+CO2		NO+CO	
	02+	04+	H30+	M2	H30+	M2
40.	1.38E-01	3.17E+00	2.81E+00	7.37E-03	2.56E-03	7.74E+00
42.	6.83E-01	5.40E+00	6.69E+00	1.80E-02	4.14E-03	6.01E-01
44.	1.59E+00	1.15E+01	1.14E+01	4.25E-02	7.37E-03	1.47E+00
46.	5.21E+00	1.57E+01	1.93E+01	1.03E+01	1.22E-02	2.27E+01
48.	1.57E+01	2.66E+01	3.25E+01	2.38E+01	3.78E+02	3.84E+00
50.	3.94E+01	4.16E+01	5.06E+01	3.61E+01	4.93E+01	4.46E+01
52.	7.67E+01	6.19E+01	7.45E+01	5.32E+01	9.92E+01	1.98E+01
54.	1.25E+02	8.26E+01	9.69E+01	7.94E+01	1.61E+02	4.16E+02
56.	1.75E+02	1.10E+02	1.29E+02	9.25E+01	2.10E+02	6.10E+01
58.	2.05E+02	1.37E+02	1.57E+02	1.12E+02	2.45E+02	1.38E+02
60.	2.37E+02	1.71E+02	1.98E+02	1.38E+02	3.05E+02	2.52E+02
62.	2.99E+02	2.68E+02	2.27E+02	1.66E+02	4.20E+02	3.25E+02
64.	3.43E+02	2.92E+02	2.68E+02	1.90E+02	5.10E+02	5.10E+02
66.	4.33E+02	3.05E+02	3.09E+02	2.18E+02	7.12E+03	7.35E+02
68.	5.10E+02	3.62E+02	3.47E+02	2.44E+02	1.92E+02	1.06E+03
70.	7.22E+02	4.33E+02	3.85E+02	2.70E+02	2.66E+02	2.32E+02
72.	1.00E+03	4.98E+02	3.98E+02	2.78E+02	5.08E+02	3.37E+02
74.	1.55E+03	5.77E+02	4.23E+02	6.87E+02	9.15E+02	5.10E+02
76.	2.95E+03	7.04E+02	4.55E+02	9.48E+02	1.24E+03	7.89E+03
78.	7.00E+03	7.53E+02	4.17E+02	2.77E+02	2.17E+03	5.39E+03
80.	1.49E+04	3.38E+02	1.49E+02	3.37E+02	1.09E+02	8.25E+03
82.	1.73E+04	7.98E+01	2.84E+02	8.37E+01	4.88E+01	4.75E+01
84.	1.05E+04	2.69E+01	7.51E+01	4.12E+00	1.07E+01	1.22E+01
86.	1.76E+04	1.00E+01	2.22E+00	1.12E+00	8.86E+00	2.93E+00
88.	1.71E+04	4.01E+00	6.58E+01	3.00E+01	1.08E+04	1.66E+04
90.	1.63E+04	1.59E+00	1.97E+01	7.66E+02	5.73E+02	1.90E+04
					9.30E-02	2.62E-05
ALTITUDE	NO+CO2		NO+H2O		NO+H2O	
	NO+H2O-N2	NO+H2O-CO2	NO+H2O	NO+H2O	NO+H2O	NO+H2O
46.	1.05E+00	1.91E-02	8.61E-04	2.61E-01	1.91E-02	6.55E-04
48.	1.79E+00	4.97E-03	1.48E-02	2.54E-03	4.44E-03	1.48E-03
50.	3.07E+00	1.24E-01	2.54E-03	7.61E-01	1.24E-01	2.19E-01
52.	5.22E+00	3.13E-01	3.20E+00	3.12E-01	3.12E-01	3.10E-01
54.	8.87E+00	7.66E-01	7.38E-03	2.02E+00	7.38E-03	2.03E+00
56.	1.41E+01	1.66E+00	1.15E-02	3.47E+00	1.15E-02	3.46E+00
58.	2.04E+01	3.22E+00	1.77E-02	6.15E+00	1.77E-02	6.13E+00
60.	3.61E+01	6.87E+00	2.28E-02	6.85E+00	2.28E-02	6.82E+00
62.	6.38E+01	1.24E+01	3.58E-02	9.93E+00	8.93E+00	7.79E+00
64.	9.35E+01	2.20E+01	1.00E+01	1.25E+01	1.07E+01	1.24E+01
66.	1.38E+01	1.71E+01	4.37E-02	1.38E+01	1.76E+01	1.24E+01
68.	2.42E+01	2.47E+01	5.04E-02	5.04E+01	4.35E-02	3.46E+01
70.	7.02E+01	3.35E+01	5.75E-02	1.72E+01	3.26E+01	5.51E-02
72.	7.72E+01	4.51E+01	6.22E-02	1.87E+01	4.36E+01	6.13E-02
74.	7.36E+01	9.14E+01	5.06E-02	1.61E+01	7.42E+01	5.77E-02
76.	7.45E+01	1.09E+02	5.28E-02	1.51E+01	7.61E+01	5.05E+01
78.	8.35E+01	1.35E+02	5.19E-02	1.44E+01	8.45E+01	4.32E+02
80.	8.66E+01	1.27E+02	3.63E-02	9.53E+00	6.13E+02	4.50E+02
82.	8.18E+01	8.71E+01	1.87E-02	4.62E+00	5.19E+01	5.94E+01
84.	6.29E+01	5.19E+01	8.26E-03	1.89E+00	3.22E+00	4.76E+01
86.	3.03E+01	3.66E+01	3.66E-03	7.95E-01	1.69E-01	4.56E+02
88.	1.94E+01	1.49E+01	1.24E-03	2.30E-01	1.97E-04	5.16E-03
90.	1.21E+01	6.66E+00	3.82E-04	6.23E-02	7.11E-02	3.89E-04

Table 3. Complete Printout of Calculations for 2110 UT, 2 November 1969 (Cont)

ALTITUDE	LA	LA33A	Q/E**2	PSUN	MSUM+E	INT.	SP	INT.	E
40.	4.31E+02	1.75F+04	6.14E+04	8.15E+04	8.13E+04	8.15E+04	6.32E+00	4.66E+00	4.00E+02
41.	2.50E+02	5.26E+03	1.69E+04	9.05E+04	9.05E+04	9.05E+04	2.04E+01	1.72E+01	5.00E+02
42.	1.44E+02	1.66E+03	1.01E+05	1.01E+05	1.01E+05	1.01E+05	6.53E+01	5.43E+01	6.40E+02
43.	8.04E+01	6.99E+02	2.17E+01	2.17E+01	2.17E+01	2.17E+01	1.10E+05	1.05E+05	1.00E+02
44.	4.60E+01	2.66E+02	3.15E+02	3.15E+02	3.15E+02	3.15E+02	1.10E+05	1.05E+05	1.00E+02
45.	3.00E+01	2.66E+02	5.39E+01	5.39E+01	5.39E+01	5.39E+01	1.15E+05	1.15E+05	1.00E+03
46.	2.50E+01	2.66E+02	1.15E+02	1.15E+02	1.15E+02	1.15E+02	1.15E+05	1.15E+05	1.00E+03
47.	2.02E+01	1.11E+02	1.21E+03	1.21E+03	1.21E+03	1.21E+03	1.19E+05	1.12E+05	1.12E+03
48.	2.07E+01	4.02E+01	3.02E+04	9.43E+04	9.55E+04	9.55E+04	1.13E+05	9.58E+04	2.85E+03
49.	9.46E+00	1.69E+01	1.02E+04	7.12E+04	7.33E+04	7.33E+04	1.01E+05	4.46E+03	1.39E+03
50.	5.42E+00	7.92E+00	3.91E+05	5.32E+04	5.32E+04	5.32E+04	8.16E+04	5.32E+04	5.69E+03
51.	3.01E+00	3.74E+00	1.69E+05	4.01E+04	4.01E+04	4.01E+04	7.71E+04	4.01E+04	5.97E+03
52.	2.04E+00	1.01E+05	3.17E+04	3.18E+04	3.18E+04	3.18E+04	6.99E+04	3.18E+04	6.44E+03
53.	1.32E+00	9.31E+01	6.31E+06	2.71E+04	2.71E+04	2.71E+04	6.17E+04	2.70E+04	1.38E+04
54.	7.06E+01	5.04E+01	4.27E+05	2.42E+04	2.41E+04	2.41E+04	5.66E+04	2.41E+04	1.30E+03
55.	3.85E+01	2.59E+01	3.12E+05	2.22E+04	2.21E+04	2.21E+04	5.11E+04	2.21E+04	9.66E+02
56.	2.23E+01	1.59E+01	2.55E+05	2.03E+04	2.11E+04	2.11E+04	4.74E+04	2.11E+04	8.51E+02
57.	1.26E+01	8.43E+02	2.17E+06	1.98E+04	1.98E+04	1.98E+04	4.13E+04	1.98E+04	7.20E+02
58.	7.06E+02	5.60E+02	1.89E+06	1.03E+04	1.04E+04	1.04E+04	3.16E+04	1.04E+04	5.00E+02
59.	3.91E+02	2.67E+02	1.64E+06	1.76E+15	1.77E+06	1.77E+06	3.53E+04	1.77E+06	1.77E+06
60.	2.15E+02	1.27E+02	1.34E+06	1.82E+04	1.66E+04	1.66E+04	3.13E+04	1.66E+04	2.02E+06
61.	1.20E+02	6.05E+03	9.03E+07	2.16E+04	2.18E+04	2.18E+04	3.76E+04	2.18E+04	1.60E+06
62.	3.23E+03	9.43E+04	5.03E+07	2.88E+04	2.89E+04	2.89E+04	3.24E+04	2.89E+04	2.89E+04
63.	1.70E+03	6.25E+05	4.30E+07	3.21E+04	3.20E+04	3.20E+04	3.32E+04	3.20E+04	3.20E+04
64.	9.55E+04	2.43E+05	4.22E+07	3.37E+04	3.37E+04	3.37E+04	3.66E+04	3.37E+04	3.37E+04
65.	1.03E+05	4.31E+07	3.45E+07	3.46E+04	3.45E+04	3.45E+04	3.57E+04	3.45E+04	3.45E+04
66.	9.96E+04	1.03E+05	3.33E+08	3.56E+04	3.56E+04	3.56E+04	3.67E+04	3.56E+04	3.56E+04
67.	2.32E+04	4.46E+05	4.35E+07	3.23E+04	3.25E+04	3.25E+04	3.71E+04	3.25E+04	3.25E+04
68.	2.02E+04	4.35E+06	4.35E+07	3.23E+04	3.25E+04	3.25E+04	3.71E+04	3.25E+04	3.25E+04

Table 4. Same as for Table 3 Except  $k_{43}$  as in Table 1. The first set of altitude listings is omitted since it is the same as for Table 3

ALTITUDE	E	NSUM	02-	04-	03-	03-	02-	03-	02-	03-	02-	03-
40.	4.66E+00	8.15E+04	1.02E+01	1.18E+01	1.96E+01	5.57E+01	1.26E+04	6.64E+00	1.05E+02	6.87E+04	1.05E+02	6.87E+04
42.	1.72E+01	9.06E+04	1.66E+01	3.07E+01	6.38E+01	1.43E+00	2.06E+01	2.81E+01	1.74E+02	6.10E+04	1.74E+02	6.10E+04
44.	5.43E+01	1.01E+05	1.58E+02	0.63E+02	2.56E+02	1.35E+02	5.03E+02	6.26E+02	5.01E+02	5.01E+02	5.01E+02	5.01E+02
46.	1.53E+02	1.10E+05	4.43E+02	1.95E+02	6.31E+02	6.31E+02	6.94E+02	1.97E+02	3.32E+02	3.66E+04	3.32E+02	3.66E+04
48.	4.31E+02	1.15E+05	1.06E+03	3.42E+02	1.35E+03	1.68E+03	1.06E+03	6.48E+03	4.37E+02	2.84E+04	4.37E+02	2.84E+04
50.	9.97E+02	1.11E+05	2.17E+03	5.33E+02	2.59E+03	2.06E+03	6.48E+03	6.48E+03	6.77E+02	5.62E+02	2.05E+02	5.62E+02
52.	2.11E+03	9.36E+04	3.76E+03	6.92E+03	3.96E+03	2.32E+01	7.14E+04	9.56E+02	6.33E+02	1.27E+04	6.33E+02	1.27E+04
54.	4.97E+03	6.96E+04	4.97E+03	7.25E+03	6.39E+03	2.15E+01	5.13E+03	1.07E+01	5.97E+02	7.22E+03	1.07E+01	7.22E+03
56.	5.95E+03	4.72E+04	5.92E+03	6.66E+03	5.86E+03	1.9E+01	3.25E+04	1.08E+03	4.61E+02	3.35E+03	4.61E+02	3.35E+03
58.	8.44E+03	3.16E+04	6.40E+03	5.85E+03	3.20E+03	1.30E+01	4.94E+04	2.92E+02	1.27E+03	2.92E+02	1.27E+03	2.92E+02
60.	1.17E+04	2.05E+04	6.15E+03	4.65E+03	2.31E+03	4.99E+00	1.06E+00	8.95E+00	1.57E+02	6.28E+02	1.57E+02	6.28E+02
62.	1.37E+04	1.31E+04	5.50E+03	3.17E+00	1.26E+03	5.54E+00	5.38E+03	7.72E+02	7.22E+02	1.28E+02	7.22E+02	1.28E+02
54.	1.53E+04	7.95E+03	4.28E+03	1.93E+00	6.27E+02	1.14E+00	2.46E+02	1.56E+02	5.01E+02	4.08E+01	3.29E+02	4.08E+01
66.	1.71E+04	4.42E+03	2.86E+03	9.87E+01	2.46E+02	1.08E+02	6.97E+02	3.89E+02	1.08E+02	1.02E+01	1.02E+01	1.02E+01
58.	1.75E+04	2.71E+03	1.95E+03	5.35E+03	1.08E+02	8.24E+01	8.01E+02	6.81E+02	4.57E+00	3.59E+00	4.57E+00	3.59E+00
70.	1.73E+04	1.52E+03	1.12E+03	2.47E+01	3.92E+01	4.16E+01	1.46E+02	1.51E+02	1.56E+00	1.07E+00	1.07E+00	1.07E+00
72.	1.64E+04	8.18E+02	6.64E+02	1.06E+01	1.28E+01	1.32E+01	5.08E+01	8.58E+01	4.92E+01	3.01E+01	4.92E+01	3.01E+01
74.	1.53E+04	6.24E+02	4.62E+02	6.31E+02	3.73E+02	6.99E+01	4.66E+01	4.66E+01	4.66E+01	4.66E+01	4.66E+01	4.66E+01
76.	1.62E+04	2.05E+02	1.63E+02	1.57E+02	8.84E+02	4.13E+02	4.92E+00	3.02E+01	3.02E+01	3.02E+01	3.02E+01	3.02E+01
78.	1.92E+04	8.81E+01	6.75E+01	4.75E+01	1.32E+02	1.79E+02	1.79E+02	1.02E+02	6.94E+01	6.92E+03	6.92E+03	6.92E+03
80.	2.66E+04	2.51E+01	1.66E+01	8.43E+04	6.39E+03	4.36E+03	7.38E+02	8.41E+02	8.41E+02	4.59E+04	4.59E+04	4.59E+04
82.	3.06E+04	5.87E+00	3.56E+00	1.33E+04	2.68E+04	1.41E+03	5.30E+03	2.30E+03	3.04E+05	6.49E+06	6.49E+06	6.49E+06
84.	3.28E+04	2.05E+01	6.97E+01	3.33E+00	6.76E+04	6.97E+04	1.00E+05	6.40E+05	1.00E+05	1.08E+06	1.08E+06	1.08E+06
86.	3.40E+04	6.27E+01	4.86E+01	9.97E+06	4.59E+06	3.69E+06	2.55E+06	3.41E+01	1.68E+06	2.75E+07	2.75E+07	2.75E+07
88.	5.12E+04	3.62E+01	2.12E+01	3.1E+06	8.36E+07	1.55E+04	7.40E+05	1.50E+01	5.41E+07	9.08E+06	9.08E+06	9.08E+06
90.	5.42E+04	1.56E+01	9.28E+02	9.53E+07	1.55E+07	4.68E+05	1.35E+05	6.58E+02	1.12E+07	1.56E+07	1.56E+07	1.56E+07
ALTITUDE	E	NSUM	04+	02+H20	M30+J4	M30+J4	M30+J2	M50+J20	M50+J20	M50+J20	M50+J20	M50+J20
40.	1.33E+01	3.17E+00	5.42E+00	6.81E+00	2.61E+02	7.37E+02	7.82E+02	1.13E+01	1.35E+01	9.71E+02	7.34E+01	9.71E+02
42.	6.63E+01	5.40E+00	6.69E+00	6.78E+00	1.80E+02	6.46E+02	1.33E+01	2.79E+01	1.46E+01	2.08E+01	1.22E+03	2.08E+01
44.	1.59E+00	9.24E+00	1.18E+01	4.26E+00	7.57E+03	2.27E+01	6.66E+01	2.52E+01	7.09E+01	2.08E+03	2.08E+03	2.08E+03
46.	5.21E+00	1.57E+01	1.93E+01	1.02E+01	1.28E+02	1.28E+02	3.84E+01	1.60E+02	4.46E+01	1.87E+00	3.39E+03	1.87E+00
48.	1.57E+01	2.66E+01	3.25E+01	2.32E+01	2.38E+02	2.16E+02	6.45E+02	3.77E+02	7.77E+01	4.75E+00	5.64E+03	4.75E+00
50.	3.98E+01	4.16E+01	5.61E+01	4.93E+01	5.36E+02	4.93E+02	1.24E+02	4.93E+02	1.24E+02	6.75E+03	6.75E+03	6.75E+03
52.	7.67E+01	6.19E+01	7.45E+01	5.32E+01	9.52E+01	4.36E+02	1.47E+02	5.32E+02	1.47E+02	1.30E+01	1.30E+01	1.30E+01
54.	1.23E+02	8.26E+01	9.85E+01	7.03E+01	1.65E+00	6.53E+02	1.94E+02	2.32E+02	3.42E+02	1.74E+02	1.74E+02	1.74E+02
56.	1.75E+02	1.10E+02	2.23E+02	1.12E+02	3.96E+00	1.56E+02	5.22E+02	6.05E+02	7.46E+02	2.34E+02	2.34E+02	2.34E+02
58.	2.05E+02	1.35E+02	1.57E+02	1.12E+02	3.96E+00	1.04E+02	3.03E+02	5.65E+02	5.65E+02	2.87E+02	2.87E+02	2.87E+02
60.	2.37E+02	1.71E+02	2.08E+02	1.38E+02	6.05E+00	1.28E+02	3.67E+02	7.83E+02	3.26E+02	3.64E+02	3.64E+02	3.64E+02
62.	2.98E+02	2.06E+02	2.27E+02	1.61E+02	6.81E+00	1.50E+02	4.20E+02	9.88E+02	3.11E+02	4.35E+02	4.35E+02	4.35E+02
64.	3.45E+02	2.52E+02	2.66E+02	1.90E+02	1.30E+01	1.78E+01	4.81E+02	1.18E+02	2.71E+02	1.91E+02	5.29E+02	5.29E+02
66.	4.39E+02	3.05E+02	3.09E+02	2.18E+02	2.04E+01	2.04E+01	5.32E+02	1.29E+02	1.29E+02	2.64E+02	6.29E+02	6.29E+02
68.	5.11E+02	3.62E+02	3.48E+02	2.45E+02	2.66E+01	2.30E+01	5.74E+02	1.32E+02	1.32E+02	3.30E+02	7.33E+02	7.33E+02
70.	7.22E+02	4.33E+02	3.86E+02	2.71E+02	3.68E+01	2.54E+01	6.03E+02	1.06E+02	1.27E+02	4.61E+02	8.56E+02	8.56E+02
72.	1.00E+03	5.91E+02	4.01E+02	3.08E+02	5.11E+01	2.63E+01	5.92E+02	1.15E+02	1.45E+02	4.04E+02	9.61E+02	9.61E+02
74.	1.57E+03	5.61E+02	4.26E+02	2.96E+02	6.94E+01	2.78E+01	5.85E+02	1.00E+02	1.43E+02	4.84E+02	8.86E+02	8.86E+02
76.	2.99E+03	7.16E+02	4.62E+02	3.17E+02	9.67E+01	2.97E+01	5.64E+02	1.11E+02	1.52E+01	5.29E+03	1.71E+01	5.29E+03
78.	7.18E+03	7.79E+02	4.30E+02	2.85E+02	1.13E+02	2.56E+01	4.20E+02	4.73E+02	7.27E+00	3.32E+03	3.14E+01	3.32E+03
80.	1.52E+04	3.40E+02	1.55E+02	9.81E+01	5.00E+01	6.76E+01	9.47E+01	5.76E+01	7.46E+01	5.48E+01	5.48E+01	5.48E+01
82.	2.89E+04	6.16E+01	2.90E+01	1.73E+01	1.11E+01	1.12E+01	9.00E+01	3.3E+02	1.06E+02	5.03E+01	5.03E+01	5.03E+01
84.	1.87E+04	2.72E+01	7.61E+00	4.21E+00	3.12E+00	2.32E+00	1.47E+00	1.72E+00	1.47E+00	2.86E+00	5.47E+01	5.47E+01
86.	1.80E+04	2.23E+00	1.16E+00	9.02E+00	6.33E+00	6.33E+00	2.85E+00	2.85E+00	2.85E+00	4.82E+00	4.82E+00	4.82E+00
88.	1.73E+04	4.02E+00	6.71E+01	3.03E+01	2.40E+01	1.20E+01	3.92E+02	5.24E+01	2.89E+01	3.76E+01	3.76E+01	3.76E+01
90.	1.63E+04	1.61E+00	1.97E+01	7.71E+02	5.76E+02	2.02E+05	4.63E+03	9.38E+02	2.02E+05	2.65E+06	1.86E+06	2.74E+06

Table 4. Same as for Table 3 Except  $k_{1,2}$  as in Table 1 (Cont)

#### 4. NUMERICAL EXAMPLE: Nighttime

Table 5 contains charged particle concentrations appropriate to SPE conditions during the night of 3 November 1969 at Ft. Churchill, Canada. The ionization production rates, principal constituents, and temperatures are identical to those used in our report<sup>1</sup> dealing with a model for the nighttime steady-state disturbed D-region. Our current, more advanced model results are not extremely different in regards to [e] as compared to our previous effort. The major difference, a somewhat lower [e] now in the 80-65 km region is actually in better accord with the data. The results in Table 5 were obtained with  $k_{43} \neq 0$ . Uncertainties in the  $\text{NO}^+$  chemistry and the chosen NO profile notwithstanding, it still is worthwhile to point out that the calculations accomplished with the Table 1 value for  $k_{43}$  resulted in an  $\text{NO}^+$  concentration at 70 km of  $2 \times 10^2 \text{ cm}^{-3}$ , far below the value in Table 5 which is in good agreement with the data.<sup>2</sup> The major positive ions are plotted in Figure 4. Below about 60-65 km, the positive ions are in thermodynamic equilibrium.

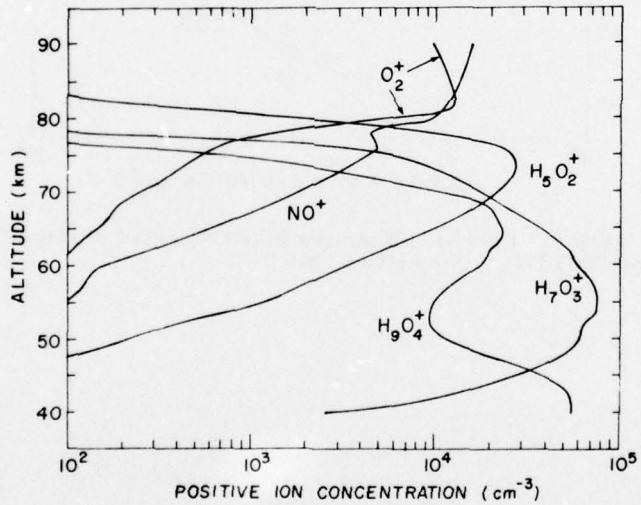


Figure 4. Principal Positive Ions Computed (Table 5) for 0605 UT, 3 November 1969, the Time of Launch for Black Brant Rocket 17.758

The negative ion populations (Figure 5) are, undoubtedly, as noted earlier, subject to considerable hydration at night. This possibility has little impact on [e] unless the hydrated negative ions have much different ion-ion recombination rates with oxonium ions than do the parent, unhydrated ions. The little experimental evidence in this regard does not favor this possibility which is attested to by the rather good agreement attained between model and data for [e].

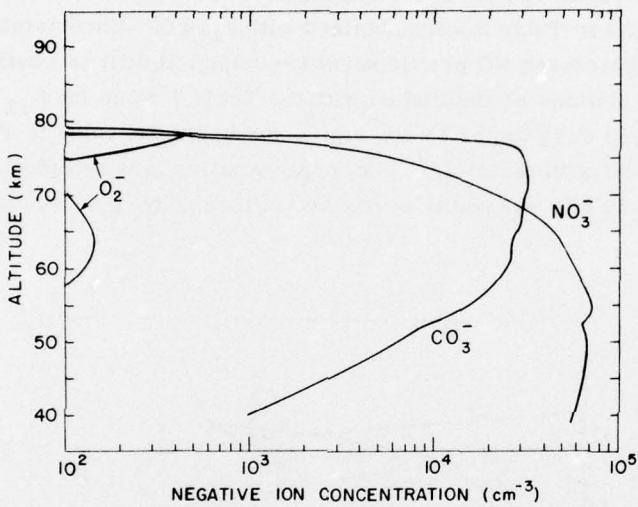


Figure 5. Principal Negative Ions Computed (Table 5) for 0605 UT, 3 November 1969

Table 5. Complete Printout of Calculations for 0605 UT, 3 November 1969. See Table 3 caption for further description of the table. Rate coefficient  $k_{4,3}$  was set to zero

4. LATITUDE	TEMP									
	0	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
60.	1.00E+00	1.60E+16	4.96E+11	2.00E+00	2.29E+13	7.63E+16	2.55E+12	7.63E+09	7.63E+16	2.51E+12
42.	1.60E+00	1.17E+16	2.50E+11	5.37E+16	9.00E+00	1.68E+13	5.60E+10	0.	5.60E+16	2.46E+12
46.	2.50E+00	8.80E+15	1.50E+11	5.37E+15	6.00E+01	1.26E+13	5.20E+10	0.	6.20E+08	2.46E+12
46.	3.90E+00	6.49E+15	2.52E+16	2.52E+16	2.00E+02	9.38E+12	3.10E+10	0.	6.40E+08	3.10E+16
46.	6.40E+00	4.82E+15	8.00E+10	2.52E+16	1.00E+03	6.08E+12	2.30E+10	0.	6.40E+08	2.51E+12
50.	1.00E+01	3.71E+15	1.39E+15	3.10E+10	5.31E+12	1.49E+12	1.20E+10	0.	3.20E+08	2.30E+16
52.	1.50E+01	2.83E+15	2.20E+10	1.05E+16	2.00E+04	4.05E+12	1.35E+10	0.	1.70E+08	2.58E+12
56.	2.44E+01	2.20E+15	1.30E+10	1.30E+15	3.00E+04	3.15E+12	1.05E+10	0.	1.30E+08	2.37E+12
56.	3.75E+01	1.68E+15	9.00E+09	6.25E+15	3.00E+05	2.60E+12	9.00E+09	0.	1.00E+08	6.00E+15
58.	6.10E+01	1.36E+15	6.60E+09	5.00E+15	7.00E+05	1.92E+12	6.40E+09	0.	7.30E+07	6.40E+15
50.	1.00E+02	1.04E+15	5.20E+09	4.98E+15	7.00E+06	1.49E+12	6.37E+09	0.	5.70E+07	6.37E+15
52.	2.48E+02	8.17E+15	4.80E+09	3.05E+15	6.00E+06	1.17E+12	3.90E+09	0.	6.70E+07	3.90E+15
64.	6.20E+02	6.29E+16	4.30E+09	2.33E+15	4.00E+06	9.00E+11	3.00E+09	0.	4.00E+07	3.00E+15
56.	2.18E+03	4.71E+15	4.10E+09	1.76E+15	1.30E+02	6.75E+11	2.25E+09	0.	2.60E+07	2.25E+15
58.	1.00E+04	3.67E+15	3.70E+09	1.37E+15	1.80E+07	5.25E+11	1.55E+09	0.	1.80E+07	1.75E+15
70.	3.00E+04	2.74E+15	3.10E+09	1.02E+15	2.00E+07	3.93E+11	1.31E+09	0.	1.31E+07	2.05E+12
72.	3.00E+05	2.07E+15	3.00E+09	7.73E+14	2.00E+07	2.97E+11	9.90E+08	0.	5.00E+06	9.90E+14
74.	3.00E+06	1.57E+16	2.90E+09	5.65E+14	2.60E+07	2.25E+11	7.50E+08	0.	2.00E+06	7.50E+14
76.	6.00E+07	1.17E+15	2.50E+09	4.37E+14	5.00E+07	1.68E+11	5.60E+08	0.	3.00E+05	5.60E+14
76.	1.50E+09	8.80E+14	8.00E+08	3.29E+14	2.50E+07	1.26E+11	4.20E+08	0.	3.00E+04	4.20E+14
80.	1.00E+10	6.29E+15	2.00E+07	2.34E+14	2.60E+07	9.00E+11	3.00E+08	0.	1.30E+02	2.34E+12
82.	9.00E+10	4.61E+13	3.00E+07	1.72E+14	2.70E+07	6.60E+11	2.20E+08	0.	2.20E+14	2.00E+12
56.	1.50E+11	3.35E+13	5.00E+07	1.25E+14	3.00E+07	4.80E+11	1.50E+08	0.	1.60E+14	2.09E+12
46.	2.50E+11	2.81E+13	3.37E+13	3.00E+07	3.60E+07	3.60E+11	1.20E+08	0.	1.20E+14	2.09E+12
46.	2.70E+11	1.80E+13	9.00E+07	6.71E+13	6.00E+07	2.58E+11	6.50E+11	0.	6.60E+13	2.10E+12
90.	3.20E+11	1.29E+11	7.00E+07	6.75E+13	4.50E+07	1.80E+11	6.12E+07	0.	6.12E+13	2.11E+12
NSUM										
40.	5.00E-01	5.63E+04	0.2-	0.4-	0.6-	0.7-	0.8-	0.9-	1.0-	ND2-
42.	9.13E-01	6.19E+04	1.24E+00	2.33E+00	4.46E+00	4.05E+02	3.72E+02	2.00E+03	3.80E+12	6.05E+16
44.	1.73E-01	6.56E+04	4.83E+03	1.00E+00	2.00E+02	7.00E+02	5.47E+02	3.00E+03	2.00E+11	6.35E+16
46.	3.49E-01	6.83E+04	4.54E+00	2.00E+02	7.00E+01	3.00E+01	3.00E+03	2.00E+11	6.34E+16	6.34E+16
48.	6.66E+00	7.07E+04	1.50E+04	3.68E+01	2.00E+02	7.00E+01	7.30E+01	4.99E+03	1.07E+10	6.65E+16
50.	1.17E+01	7.26E+04	1.26E+04	3.00E+02	2.00E+01	1.00E+01	6.04E+01	6.04E+03	5.01E+10	1.19E+16
52.	1.99E+01	7.20E+04	1.18E+01	4.00E+02	4.00E+01	1.40E+01	1.11E+03	1.11E+03	9.00E+10	9.00E+16
54.	6.57E+01	6.48E+04	5.10E+01	7.44E+02	5.94E+02	2.49E+01	1.39E+01	1.08E+01	1.17E+02	7.08E+16
56.	6.25E+01	6.64E+04	7.92E+01	8.11E+02	7.63E+01	3.59E+01	1.78E+01	3.05E+00	7.20E+12	6.65E+16
58.	1.25E+02	6.41E+04	1.05E+02	9.60E+02	7.88E+02	4.02E+01	2.16E+01	2.16E+01	1.77E+07	7.78E+11
50.	1.97E+02	6.09E+04	1.29E+02	9.32E+02	8.78E+02	4.90E+01	2.42E+01	3.19E+01	9.75E+07	9.75E+11
62.	3.05E+02	7.82E+04	1.75E+02	7.95E+02	6.36E+01	5.76E+01	2.61E+01	2.63E+01	5.08E+06	5.08E+16
64.	6.72E+02	7.39E+04	1.45E+02	6.54E+02	4.46E+02	2.41E+01	6.79E+01	2.66E+01	7.72E+00	4.22E+16
56.	7.13E+02	6.79E+04	1.29E+02	1.17E+02	3.20E+02	2.16E+02	8.41E+00	8.08E+01	1.13E+01	3.33E+16
58.	9.79E+02	6.05E+04	1.05E+03	5.32E+04	1.05E+02	8.41E+00	8.08E+01	5.07E+05	1.75E+11	2.55E+16
70.	1.39E+03	5.32E+04	1.05E+04	1.05E+02	2.16E+02	8.41E+00	8.08E+01	3.05E+04	2.00E+11	2.00E+16
72.	1.63E+03	4.61E+04	8.86E+01	1.41E+02	6.57E+01	6.23E+01	3.20E+01	3.10E+01	1.39E+11	5.05E+16
74.	2.54E+03	3.96E+04	1.49E+02	1.05E+02	2.36E+01	2.36E+01	1.42E+01	1.42E+01	3.12E+02	3.12E+16
76.	3.44E+03	3.28E+04	2.05E+02	1.91E+02	4.09E+00	2.42E+00	2.84E+01	8.31E+01	3.42E+01	4.22E+16
78.	1.33E+04	2.27E+04	4.52E+02	3.18E+02	5.20E+00	3.12E+00	2.94E+01	1.31E+03	4.72E+00	4.72E+16
80.	2.00E+04	3.96E+01	2.25E+01	1.14E+03	1.63E+02	8.61E+03	2.37E+01	1.68E+01	2.26E+12	5.07E+16
82.	6.42E+04	5.22E+00	2.98E+00	1.12E+04	2.35E+04	1.25E+03	4.92E+03	2.23E+00	3.48E+04	8.32E+16
84.	2.54E+04	1.68E+00	9.07E+01	6.33E+05	2.41E+05	5.53E+04	9.47E+04	7.49E+04	1.02E+05	1.71E+16
86.	2.53E+04	6.43E+01	3.64E+01	7.54E+01	3.44E+06	2.40E+06	1.15E+04	2.01E+04	2.75E+01	9.09E+16
88.	2.70E+01	1.54E+01	1.54E+01	6.16E+06	2.26E+06	6.16E+07	5.79E+05	1.16E+01	2.66E+16	1.44E+16
90.	2.51E+04	1.15E+01	6.50E+02	6.80E+02	1.12E+07	3.41E+05	9.93E+06	4.93E+02	6.30E+07	2.00E+16

Table 5. Complete Printout of Calculations for 0605 UT, 3 November 1969 (Cont)

ALTITUDE	02+ H20		H30+ JM		H30+ N2		H30+ CO2		H50+ CO2		H50+ N2	
	04+	1.49E+00	1.38E+00	1.28E+00	1.26E+00	1.24E+00	1.22E+00	1.20E+00	1.18E+00	1.16E+00	1.14E+00	1.12E+00
40.	6.51E-02	2.40E+00	6.28E+00	2.08E+00	6.28E+00	2.08E+00	6.122E+00	2.06E+00	6.122E+00	2.06E+00	6.122E+00	2.05E+00
42.	2.21E-01	3.69E+00	4.61E+00	3.29E+00	4.61E+00	3.29E+00	5.17E+00	3.06E+00	5.17E+00	3.06E+00	5.17E+00	3.05E+00
44.	6.33E-01	5.42E+00	6.77E+00	4.84E+00	5.42E+00	6.77E+00	4.19E+00	5.35E+00	4.19E+00	5.35E+00	4.19E+00	5.35E+00
46.	1.77E+00	7.82E+00	9.78E+00	6.98E+00	7.82E+00	9.78E+00	7.16E+00	6.99E+00	7.16E+00	6.99E+00	7.16E+00	6.98E+00
48.	6.62E+00	1.08E+01	1.36E+01	9.58E+00	1.08E+01	1.36E+01	1.32E+01	8.29E+00	1.32E+01	8.29E+00	1.32E+01	8.29E+00
50.	1.08E+01	1.41E+01	1.76E+01	1.36E+01	1.41E+01	1.76E+01	1.71E+01	1.37E+01	1.71E+01	1.37E+01	1.71E+01	1.36E+01
52.	1.74E+01	2.56E+01	3.20E+01	2.28E+01	2.56E+01	3.20E+01	2.52E+01	2.12E+02	2.52E+01	2.12E+02	2.52E+01	2.11E+02
54.	3.79E+01	5.67E+01	6.59E+01	4.74E+01	5.67E+01	6.59E+01	6.84E+01	5.35E+01	6.84E+01	5.35E+01	6.84E+01	5.34E+01
56.	6.55E+01	9.39E+01	1.04E+02	7.49E+01	9.39E+01	1.04E+02	1.03E+02	5.66E+01	1.03E+02	5.66E+01	1.03E+02	5.65E+01
58.	6.55E+01	5.54E+01	6.92E+01	4.98E+01	5.54E+01	6.92E+01	6.40E+01	4.39E+01	6.40E+01	4.39E+01	6.40E+01	4.38E+01
60.	7.43E+01	1.00E+02	7.18E+01	6.40E+01	1.00E+02	7.18E+01	7.17E+00	4.39E+01	7.17E+00	4.39E+01	7.17E+00	4.38E+01
62.	1.28E+02	9.47E+01	1.19E+02	8.40E+01	1.28E+02	9.47E+01	9.45E+00	5.73E+00	9.45E+00	5.73E+00	9.45E+00	5.72E+00
64.	1.28E+02	1.29E+02	1.55E+02	1.11E+02	1.28E+02	1.29E+02	1.28E+02	7.93E+00	1.28E+02	7.93E+00	1.28E+02	7.92E+00
66.	1.60E+02	1.29E+02	1.55E+02	1.11E+02	1.60E+02	1.29E+02	1.28E+02	7.93E+00	1.28E+02	7.93E+00	1.28E+02	7.92E+00
68.	1.88E+02	1.51E+02	1.99E+02	1.49E+02	1.88E+02	1.51E+02	1.50E+02	1.49E+02	1.50E+02	1.49E+02	1.50E+02	1.49E+02
70.	2.51E+02	1.90E+02	2.37E+02	1.89E+02	2.51E+02	1.90E+02	1.90E+02	1.89E+02	1.90E+02	1.89E+02	1.90E+02	1.89E+02
72.	3.35E+02	2.29E+02	2.76E+02	3.42E+02	3.35E+02	2.29E+02	2.47E+02	5.64E+01	2.29E+02	2.47E+02	5.64E+01	2.28E+02
74.	4.52E+02	3.20E+02	3.53E+02	4.32E+02	4.52E+02	3.20E+02	3.42E+02	8.80E+01	3.20E+02	3.42E+02	8.80E+01	3.19E+02
76.	6.36E+02	4.36E+02	4.89E+02	6.12E+02	6.36E+02	4.36E+02	4.36E+02	2.70E+01	6.36E+02	4.36E+02	2.70E+01	6.35E+02
78.	1.27E+03	7.30E+02	1.09E+03	1.27E+03	1.27E+03	7.30E+02	7.30E+02	2.38E+01	7.30E+02	7.30E+02	2.38E+01	7.30E+02
80.	7.31E+03	2.71E+02	3.07E+02	2.00E+02	7.31E+03	2.71E+02	2.00E+02	1.05E+02	7.31E+03	2.71E+02	2.00E+02	7.31E+03
82.	1.28E+04	5.60E+02	1.78E+01	5.60E+02	1.28E+04	5.60E+02	1.78E+01	2.36E+01	1.28E+04	5.60E+02	1.78E+01	2.35E+01
84.	1.25E+06	1.80E+01	1.04E+01	1.78E+01	1.25E+06	1.80E+01	1.04E+01	8.06E+00	1.25E+06	1.80E+01	1.04E+01	1.25E+06
86.	1.17E+06	6.36E+00	5.87E+00	3.22E+00	1.17E+06	6.36E+00	5.87E+00	2.77E+00	1.17E+06	6.36E+00	5.87E+00	1.17E+06
88.	2.44E+00	2.44E+00	2.02E+00	9.07E+00	2.44E+00	2.44E+00	9.07E+00	4.32E+00	2.44E+00	2.44E+00	9.07E+00	2.44E+00
90.	9.53E+03	9.35E+01	6.94E+01	3.13E+01	9.45E+01	9.35E+01	6.94E+01	2.69E+01	9.45E+01	9.35E+01	6.94E+01	2.68E+01
40.	9.91E-03	2.28E-02	6.79E-02	1.02E-02	9.91E-03	2.28E-02	6.79E-02	4.10E-04	9.91E-03	2.28E-02	6.79E-02	4.09E-04
42.	4.97E-01	4.12E-01	2.04E-01	2.27E-01	4.97E-01	4.12E-01	2.04E-01	4.96E-01	4.12E-01	2.04E-01	4.96E-01	4.11E-01
44.	1.23E+00	4.97E-02	1.02E-03	4.97E-02	1.23E+00	4.97E-02	1.02E-03	4.96E-02	1.23E+00	4.97E-02	1.02E-03	4.96E-02
46.	1.81E+00	1.08E-03	1.49E-03	1.08E-03	1.81E+00	1.08E-03	1.49E-03	1.07E-03	1.81E+00	1.08E-03	1.49E-03	1.07E-03
48.	2.61E+00	2.36E-01	2.26E-01	2.36E-01	2.61E+00	2.36E-01	2.26E-01	2.25E-01	2.61E+00	2.36E-01	2.26E-01	2.25E-01
50.	3.64E+00	7.27E-01	3.87E-03	1.51E+00	3.64E+00	7.27E-01	3.87E-03	7.26E-01	3.64E+00	7.27E-01	3.87E-03	7.26E-01
52.	6.44E+00	1.66E+01	2.30E+01	4.20E+00	6.44E+00	1.66E+01	2.30E+01	6.39E+00	6.44E+00	1.66E+01	2.30E+01	6.38E+00
54.	8.44E+00	2.30E+01	2.97E+00	2.30E+00	8.44E+00	2.30E+01	2.97E+00	9.75E+00	8.44E+00	2.30E+01	2.97E+00	9.74E+00
56.	1.19E+01	2.99E+00	9.78E+00	2.99E+00	1.19E+01	2.99E+00	9.78E+00	9.75E+00	1.19E+01	2.99E+00	9.78E+00	9.73E+00
58.	1.45E+01	4.15E+00	1.22E+00	3.55E+00	1.45E+01	4.15E+00	1.22E+00	4.10E+00	1.45E+01	4.15E+00	1.22E+00	4.09E+00
60.	1.88E+01	6.09E+00	9.43E+00	5.78E+00	1.88E+01	6.09E+00	9.43E+00	9.41E+00	1.88E+01	6.09E+00	9.43E+00	9.39E+00
62.	2.35E+01	9.43E+00	1.93E+00	5.78E+00	2.35E+01	9.43E+00	1.93E+00	1.92E+00	2.35E+01	9.43E+00	1.93E+00	1.92E+00
64.	3.04E+01	1.46E+01	2.51E+01	7.52E+00	3.04E+01	1.46E+01	2.51E+01	7.50E+00	3.04E+01	1.46E+01	2.51E+01	7.49E+00
66.	3.9E+01	2.36E+01	3.26E+01	9.75E+00	3.9E+01	2.36E+01	3.26E+01	9.73E+00	3.9E+01	2.36E+01	3.26E+01	9.71E+00
68.	4.70E+01	3.25E+01	3.87E+02	1.16E+01	3.25E+01	3.87E+02	1.16E+01	3.12E+01	3.25E+01	3.87E+02	1.16E+01	3.11E+01
70.	5.63E+01	4.95E+01	4.67E+02	1.40E+01	5.63E+01	4.95E+01	4.67E+02	1.38E+01	5.63E+01	4.95E+01	4.67E+02	1.37E+01
72.	6.47E+01	6.9E+01	5.28E+02	1.58E+02	6.47E+01	6.9E+01	5.28E+02	1.56E+02	6.47E+01	6.9E+01	5.28E+02	1.55E+02
74.	7.09E+01	9.43E+01	5.78E+02	1.71E+02	7.09E+01	9.43E+01	5.78E+02	1.70E+02	7.09E+01	9.43E+01	5.78E+02	1.70E+02
76.	7.22E+01	1.19E+02	5.72E+02	1.70E+02	7.22E+01	1.19E+02	5.72E+02	1.70E+02	7.22E+01	1.19E+02	5.72E+02	1.70E+02
78.	4.73E+01	8.45E+01	3.26E+02	9.32E+00	5.71E+01	8.45E+01	3.26E+02	9.30E+00	5.71E+01	8.45E+01	3.26E+02	9.28E+00
80.	6.41E+01	1.17E+02	2.04E+02	5.22E+01	6.41E+01	1.17E+02	2.04E+02	5.20E+01	6.41E+01	1.17E+02	2.04E+02	5.18E+01
82.	5.63E+01	9.45E+01	9.71E+03	2.35E+00	6.09E+01	9.45E+01	9.71E+03	2.33E+00	6.09E+01	9.45E+01	9.71E+03	2.31E+00
84.	6.08E+01	4.55E+01	3.81E+03	1.04E+00	6.08E+01	4.55E+01	3.81E+03	1.03E+00	6.08E+01	4.55E+01	3.81E+03	1.02E+00
86.	2.97E+01	1.98E+01	1.65E+03	3.46E+01	2.97E+01	1.98E+01	1.65E+03	3.45E+01	2.97E+01	1.98E+01	1.65E+03	3.44E+01
88.	1.98E+01	1.98E+01	1.65E+03	3.46E+01	1.98E+01	1.98E+01	1.65E+03	3.45E+01	1.98E+01	1.98E+01	1.65E+03	3.44E+01
90.	1.24E+01	9.30E+00	5.47E+04	1.01E+01	1.62E+01	9.30E+00	5.47E+04	1.01E+01	1.62E+01	9.30E+00	5.47E+04	1.01E+01

Table 5. Complete Printout of Calculations for 0605 UT, 3 November 1969 (Cont)

ALTITUDE	LA	LANGDA	Q/E*2	PSUM	NSUM+E	INT. SP	SP	INT. F	F	0
40.	4.51E+02	1.33E-05	1.07E-03	5.03E+04	5.03E+04	5.03E+04	5.03E+04	4.22E-01	1.07E+02	
42.	2.50E+02	6.74E-02	2.72E-02	6.18E+04	6.19E+04	6.19E+04	6.19E+04	9.19E-01	9.19E-01	
44.	1.44E+02	3.66E+04	8.05E+01	6.54E+04	6.56E+04	6.56E+04	6.56E+04	1.79E+00	2.58E+02	
46.	8.04E+01	1.36E+04	2.31E+01	6.01E+04	6.03E+04	6.03E+04	6.03E+04	3.48E+00	3.48E+00	
48.	6.50E+01	1.06E+04	6.75E+00	7.02E+04	7.07E+04	7.07E+04	7.07E+04	6.66E+00	6.66E+00	
50.	2.70E+11	6.20E+03	2.33E+00	7.25E+04	7.26E+04	7.26E+04	7.26E+04	1.13E+01	1.17E+01	
52.	1.57E+01	3.63E+03	8.08E-01	7.20E+04	7.27E+04	7.20E+04	7.27E+04	2.02E+01	3.20E+02	
54.	9.65E+00	1.06E+03	2.15E-01	8.49E+04	8.54E+04	8.49E+04	8.54E+04	4.73E+01	4.48E+02	
56.	5.02E+00	1.04E+03	6.39E-02	8.66E+04	8.65E+04	8.66E+04	8.65E+04	6.31E+01	6.28E+01	
58.	3.31E+00	6.73E+02	3.00E-12	8.44E+04	8.42E+04	8.44E+04	8.42E+04	1.38E+02	1.25E+02	
60.	2.01E+00	4.11E+02	1.13E-02	8.13E+04	8.10E+04	8.13E+04	8.10E+04	2.23E+02	4.60E+02	
62.	1.22E+00	2.56E+02	5.03E-13	7.08E+04	7.05E+04	7.08E+04	7.05E+04	3.05E+02	4.60E+02	
64.	7.04E-01	1.55E+02	2.07E-03	7.45E+04	7.44E+04	7.45E+04	7.44E+04	6.75E+02	6.75E+02	
66.	3.88E-11	9.05E+01	9.04E-04	6.83E+04	6.86E+04	6.83E+04	6.86E+04	1.21E+03	1.21E+03	
68.	2.23E-01	6.18E+01	4.64E-04	6.17E+04	6.15E+04	6.17E+04	6.15E+04	1.94E+03	9.79E+02	
70.	1.25E-01	3.02E+01	2.17E-04	5.49E+04	5.45E+04	5.49E+04	5.45E+04	3.30E+03	1.39E+03	
72.	7.65E-02	2.43E+01	1.07E-04	6.08E+04	6.00E+04	6.08E+04	6.00E+04	5.30E+03	1.88E+03	
74.	3.91E-02	1.36E+01	5.49E-05	4.68E+04	4.21E+04	4.68E+04	4.21E+04	6.28E+03	2.55E+03	
76.	2.35E-12	9.95E+00	2.75E-05	3.68E+04	3.63E+04	3.68E+04	3.63E+04	3.73E+04	3.44E+03	
78.	1.20E-02	1.70E-01	1.72E-06	1.54E+04	1.56E+04	1.54E+04	1.56E+04	1.54E+04	1.32E+04	
80.	6.05E-03	1.98E-03	7.22E-07	2.00E+04	2.01E+04	2.00E+04	2.01E+04	2.04E+04	2.04E+04	
82.	3.23E-03	2.10E-03	4.67E-07	2.51E+04	2.49E+04	2.51E+04	2.49E+04	2.32E+04	2.48E+04	
84.	1.70E-13	6.61E-05	4.48E-07	2.55E+04	2.56E+04	2.55E+04	2.56E+04	2.49E+04	2.58E+04	
86.	4.93E-04	2.33E-05	4.50E-07	2.53E+04	2.54E+04	2.53E+04	2.54E+04	2.50E+04	2.54E+04	
88.	4.93E-04	1.07E-05	4.33E-07	2.51E+04	2.53E+04	2.51E+04	2.53E+04	2.63E+04	2.53E+04	
90.	2.52E-04	4.59E-06	4.61E-07	2.51E+04	2.51E+04	2.51E+04	2.51E+04	2.56E+04	2.51E+04	

## 5. NUMERICAL EXAMPLE: August 1972 SPE

The final example presented (Table 6) is for one instance during the 3 to 11 August 1972 SPE. The temperature, T, and total molecular concentration, [M] are for 1 August, 65° N, being interpolated from the CIRA 1972 models for 60° N and 70° N on 1 August. The ionization production rates are those for 1508 UT on 4 August.<sup>17</sup> Computed [e] agrees very well with data taken by the Chatanika back-scatter radar at 62 km. However, above this altitude the model predicts electron concentrations 2 to 3 times greater than those reported.<sup>17</sup> The situation is more serious below 62 km where model electron concentrations fall off more rapidly with decreasing altitude than do the data, the lowest altitude (50 km) measurement being  $1 \times 10^4 \text{ cm}^{-3}$  whereas we compute  $2.5 \times 10^3 \text{ cm}^{-3}$  (Table 6).

The disagreement is disappointing in view of the good results obtained with the model and the 2 to 5 November 1969 SPE. However, different seasonal factors may influence the important minor neutral species in such a way as to account for the differences. Note that we have used the same minor neutral concentrations O, O<sub>3</sub>, NO, NO<sub>2</sub> and O<sub>2</sub><sup>(1Δ)</sup> as previously, but N<sub>2</sub>, O<sub>2</sub>, CO<sub>2</sub> and H<sub>2</sub>O have changed since they are multiples of [M] which has been altered. We have suggested<sup>18</sup> that higher H<sub>2</sub>O concentrations, say 10 ppmv, near the 80 km region would improve the model/data agreement considerably. The rationale for higher H<sub>2</sub>O is that noctilucent-clouds are prevalent in the high latitude summer mesosphere. The situation near 50 km is much more serious since the discrepancy is nearly an order of magnitude. A higher O<sub>3</sub>, and hence O concentration would help alleviate the problem, but in fact there is evidence<sup>19</sup> that O<sub>3</sub> may have declined during this event due to the enhanced formation of NO resulting from proton ionization processes. A decrease in O<sub>3</sub>, and therefore O, not to mention an increase of NO, and hence NO<sub>2</sub><sup>-</sup>, NO<sub>3</sub><sup>-</sup>, would tend to make matters worse, if anything. The precision of the electron concentrations measured by the Chatanika radar below 60 km should be considered also. It may be that the [e] values have an important systematic error with decreasing altitude below 60 km. We note that no data is given below 50 km indicating that this is the last acceptable data point. Deterioration of the [e]-measurement may be setting in at a somewhat higher altitude. The Chatanika radar has been able to make D-region measurements only during this rather intense SPE.

17. Reagan, J. B., and Watt, T. M. (1976) Simultaneous satellite and radar studies of the D-region ionosphere during the intense solar particle events of August 1972, *J. Geophys. Res.* 81:4579-4596.
18. Swider, W., and Foley, C. I. (1977) The influence of minor atmospheric constituents on the electron loss rates of the August 4-11, 1972 and November 2-5 1969, solar proton events, *EOS*, 58:465.
19. Heath, D. F., Krueger, A. J., and Crutzen, P. J. (1971) Solar proton event: Influence on stratospheric ozone, *Science* 197:886-889.

Reagan and Watt<sup>17</sup> claimed that  $\psi$  (or SI, see Eq. (1)) for this event agreed with the results<sup>4</sup> for the 2 to 5 November 1969 SPE. However, the events were not normalized in terms of their appropriate T and [M] values. The  $\psi$  curves for the two events thus agree well, save for the 80-km region problem, only if T and [M] for the August 1972 SPE was similar to that for the 2 to 5 November 1969 event. This possibility appears to be remote. The 1 November 60°N CIRA 1972 T and [M] values used for the November SPE are corroborated by experimental<sup>20</sup> evidence.

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20. Faire, A. C., and Murphy, E. A. (1972) in Proc. COSPAR Symp. on SPE of Nov. 1969, AFCRL-72-0474, pp 445-455.

Table 6. Complete Printout of Calculations for 1508 UT, 4 August 19 $\lambda$ 2. See Table 3 caption for further description of the table. Rate coefficient  $k_{43}$  was set to zero. The solar zenith angle was 79.5°.

ALTITUDE	0		02		03		N2		C02		H20		02(10)		N2		M		TEMP
	0	0.00E+00	1.00E+09	1.94E+11	4.50E+11	7.23E+16	1.00E+09	2.74E+11	9.26E+10	2.00E+08	2.00E+10	9.26E+16	2.61E+02	3.00E+02	9.00E+02	2.61E+02	2.61E+02	2.61E+02	
0.	1.00E+09	1.00E+09	1.49E+16	2.50E+11	5.33E+16	8.00E+08	2.07E+13	6.99E+10	1.50E+10	6.00E+07	2.65E+02								
42.	1.40E+09	1.40E+09	1.13E+16	1.50E+11	4.22E+16	6.00E+08	1.65E+13	5.40E+10	1.00E+10	2.00E+07	5.40E+16	2.72E+02	5.40E+16	2.72E+02	5.40E+16	2.72E+02	2.72E+02	2.75E+02	
46.	1.80E+09	1.80E+09	6.40E+15	6.40E+10	3.25E+16	4.00E+08	4.00E+13	4.20E+10	7.00E+13	4.20E+16	4.20E+16	2.75E+02	4.20E+16	2.75E+02	4.20E+16	2.75E+02	2.75E+02	2.75E+02	
50.	2.20E+09	2.20E+09	6.91E+15	5.00E+10	2.59E+16	3.20E+08	9.90E+12	3.30E+10	1.30E+10	2.30E+06	3.30E+15	2.77E+02	3.30E+15	2.77E+02	3.30E+15	2.77E+02	2.77E+02	2.78E+02	
54.	2.90E+09	2.90E+09	5.28E+15	2.00E+10	1.97E+16	2.40E+08	7.56E+12	2.52E+10	1.50E+10	5.00E+05	2.52E+16	2.78E+02	5.00E+05	2.78E+02	5.00E+05	2.78E+02	2.78E+02	2.78E+02	
58.	3.10E+09	3.10E+09	4.19E+15	1.50E+10	1.55E+16	1.70E+08	6.00E+12	3.00E+11	1.00E+11	1.50E+10	3.00E+10	2.00E+05	1.50E+10	2.00E+05	1.50E+10	2.00E+05	2.00E+05	2.75E+02	
62.	3.50E+09	3.50E+09	3.25E+15	6.70E+09	1.21E+16	1.30E+08	4.65E+12	1.55E+10	1.55E+10	1.40E+10	1.40E+10	1.00E+05	1.55E+10	1.00E+05	1.55E+10	1.00E+05	1.55E+10	2.75E+02	
66.	3.90E+09	3.90E+09	2.62E+15	5.00E+09	9.75E+15	2.62E+08	2.75E+12	1.25E+10	1.10E+10	1.25E+16	1.25E+16	2.71E+02	1.25E+16	2.71E+02	1.25E+16	2.71E+02	2.71E+02	2.71E+02	
70.	3.60E+09	3.60E+09	2.05E+15	2.80E+09	7.65E+15	7.30E+07	2.90E+12	9.50E+09	9.00E+09	1.70E+04	9.00E+09	2.66E+02	1.70E+04	2.66E+02	1.70E+04	2.66E+02	2.66E+02	2.66E+02	
74.	3.40E+09	3.40E+09	1.84E+15	1.60E+09	6.11E+15	5.70E+07	2.35E+12	7.82E+09	6.80E+09	7.00E+03	6.80E+09	2.60E+02	7.00E+03	2.60E+02	7.00E+03	2.60E+02	2.60E+02	2.60E+02	
76.	4.50E+09	4.50E+09	1.32E+15	5.00E+08	4.92E+15	4.70E+07	6.89E+12	6.30E+09	4.70E+09										
78.	9.00E+09	9.00E+09	1.03E+15	5.00E+08	5.83E+15	5.00E+07	1.47E+12	6.90E+09	3.40E+09	1.60E+03	1.60E+03	4.70E+09							
80.	3.00E+10	3.00E+10	2.97E+15	2.80E+08	3.50E+15	3.00E+07	8.00E+09	7.80E+09	3.80E+09										
84.	9.00E+09	9.00E+09	6.29E+14	1.70E+08	2.30E+15	2.30E+07	9.00E+07	6.95E+11	2.31E+09	1.10E+09	2.31E+09								
86.	3.60E+09	3.60E+09	3.67E+14	7.00E+07	2.70E+15	7.00E+07	5.20E+11	7.00E+09	1.75E+09	7.00E+09	1.75E+09								
90.	2.20E+09	2.20E+09	2.72E+14	4.70E+07	1.02E+15	2.00E+07	3.90E+11	1.30E+09											
94.	2.20E+09	2.20E+09	2.10E+14	3.10E+07	5.71E+14	2.50E+07	7.22E+11	7.40E+08	2.50E+08										
96.	2.20E+09	2.20E+09	1.55E+14	2.00E+07	5.71E+14	2.50E+07	7.22E+11	7.40E+08	2.50E+08										
98.	2.20E+09	2.20E+09	1.05E+14	2.00E+07	5.71E+14	2.50E+07	7.22E+11	7.40E+08	2.50E+08										
100.	3.20E+11	3.20E+11	2.10E+13	9.00E+07	7.81E+13	4.00E+07	3.00E+11	4.00E+08	1.00E+08										
104.	1.34E+13	1.34E+13	7.00E+07	4.50E+07	4.95E+13	4.50E+07	3.20E+08	4.50E+07	1.90E+08										
ALTITUDE	0	0.51E+01																	
0-	0	3.72E+00	7.19E+02	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
4-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
8-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
12-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
16-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
20-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
24-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
28-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
32-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
36-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
40-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
44-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
48-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
52-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
56-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
60-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
64-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
68-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
72-	0	3.72E+00	6.10E+03	6.10E+03	3.75E+03	1.10E+01	1.78E+03	2.56E+01	1.78E+03	0.51E+01									
76-	0	3.72E+00	6.10E+03	6.															

Table 6. Complete Printout of Calculations for 1508 UT, 4 August 1972 (Cont)

ALTITUDE	024+H20		H30+34		H30+02		H30+02		H50+202		H50+202		
	04+	04+H42	2.43E+02	3.35E+02	2.27E+02	8.76E-01	2.11E-01	6.29E+02	1.35E+03	6.31E+02	1.35E+03	6.31E+02	3.79E+01
40.	4.31E+01	1.05E+02	2.56E+02	3.39E+02	2.27E+02	8.76E-01	2.11E-01	6.29E+02	1.35E+03	6.31E+02	1.35E+03	6.31E+02	3.79E+01
42.	9.91E+01	2.56E+02	3.22E+02	3.98E+02	2.84E+02	1.41E+00	2.64E+01	7.47E+02	1.35E+03	6.31E+02	1.35E+03	6.31E+02	3.79E+01
44.	2.50E+02	3.22E+02	4.03E+02	4.97E+02	3.55E+02	2.32E+01	3.10E-01	9.40E+02	3.29E+03	1.47E+03	1.47E+03	1.47E+03	1.99E+02
46.	4.65E+02	4.03E+02	4.95E+02	6.04E+02	4.34E+02	3.67E+00	4.04E-01	1.20E+03	1.20E+03	5.91E+03	5.91E+03	5.91E+03	3.15E+02
48.	8.66E+02	6.04E+02	7.65E+02	9.06E+02	6.08E+02	5.08E-01	1.04E+01	1.20E+03	1.20E+03	7.76E+03	7.76E+03	7.76E+03	5.28E+02
50.	1.51E+03	7.25E+02	9.35E+02	9.35E+02	6.47E+02	9.12E+00	6.03E+01	1.07E+03	1.07E+03	1.52E+03	1.52E+03	1.52E+03	7.95E+02
52.	2.16E+03	7.94E+02	9.06E+02	9.35E+02	6.47E+02	9.12E+00	6.03E+01	1.07E+03	1.07E+03	1.52E+03	1.52E+03	1.52E+03	7.95E+02
54.	2.97E+03	9.06E+02											
56.	3.30E+03	1.04E+03											
58.	3.30E+03	1.21E+03	1.43E+03										
60.	3.37E+03	1.37E+03	1.60E+03										
62.	2.73E+03	1.47E+03	1.69E+03										
64.	2.33E+03	1.65E+03											
56.	2.97E+03	9.06E+02	1.10E+03	7.81E+02	1.38E+01	7.55E+01	1.12E+01	2.12E+03	2.12E+03	2.91E+04	2.91E+04	2.91E+04	1.21E+03
58.	3.30E+03	1.04E+03											
60.	3.37E+03	1.21E+03	1.43E+03										
62.	2.73E+03	1.47E+03	1.69E+03										
64.	2.33E+03	1.65E+03											
56.	1.94E+01	1.42E+03	1.39E+03										
58.	1.57E+03	2.03E+03	2.12E+03										
60.	1.43E+03	2.34E+03	2.75E+03	2.57E+03	2.75E+03								
62.	1.56E+03	2.75E+03											
64.	2.28E+03	3.59E+03	2.91E+03										
66.	3.59E+03	4.02E+03	3.16E+03										
68.	4.04E+03	4.04E+03	3.62E+03										
70.	4.02E+03	4.22E+03	2.67E+03										
72.	6.17E+04	1.01E+03	1.66E+02	4.37E+02	2.13E+02	1.46E+01	4.16E+01	2.36E+02	1.35E+03	5.19E+03	1.47E+03	1.47E+03	1.47E+03
74.	6.32E+04	5.78E+02	1.97E+02	9.33E+01	3.43E+01	6.37E+02	3.35E+01	1.88E+02	3.35E+01	1.88E+02	3.35E+01	1.88E+02	3.35E+01
76.	6.45E+04	1.73E+02	2.98E+02	8.00E+01	2.95E+01	6.25E+02	1.48E+02	6.94E+02	1.48E+02	6.94E+02	1.48E+02	6.94E+02	1.48E+02
78.	6.57E+04	5.05E+01	8.73E+00	2.89E+00	1.53E+00								
80.	5.37E+04	1.53E+01											
82.	5.37E+04	1.53E+01											
84.	5.37E+04	1.53E+01											
86.	5.37E+04	1.53E+01											
88.	5.37E+04	1.53E+01											
90.	5.37E+04	1.53E+01											

Table 6. Complete Printout of Calculations for 1508 UT, 4 August 1972 (Cont)

ALTITUDE	LA	LAMBDA	Q/F**2	PSUM	NSUM+E	INT. SP	INT. E	Q
40.	7.40E+02	8.25E+03	4.11E+00	7.00E+05	7.05E+05	7.04E+05	6.54E+01	3.00E+04
42.	4.22E+02	3.60E+03	6.29E-01	6.92E+05	6.31E+05	6.92E+05	1.55E+02	2.93E+04
44.	2.65E+02	1.96E+03	2.38E-01	6.81E+05	6.76E+05	6.81E+05	4.30E+02	2.88E+04
46.	1.65E+02	1.01E+03	6.47E-02	6.60E+05	6.63E+05	6.63E+05	1.16E+03	6.54E+02
48.	1.01E+02	5.17E+02	1.80E-02	6.30E+05	6.31E+05	6.32E+05	1.22E+03	2.70E+04
50.	5.99E+01	2.35E+02	4.10E-03	5.80E+05	5.83E+05	5.83E+05	7.16E+03	2.52E+03
52.	3.71E+01	1.10E+02	1.11E-03	5.11E+05	5.15E+05	5.11E+05	1.21E+04	4.61E+03
54.	2.21E+01	4.10E+01	3.38E-04	4.13E+05	4.12E+05	4.12E+05	1.81E+04	2.48E+04
56.	1.42E+01	2.50E+01	1.38E-04	3.24E+05	3.26E+05	3.24E+05	2.22E+04	2.30E+04
58.	8.55E+00	1.16E+01	5.38E-05	2.37E+05	2.39E+05	2.38E+05	1.55E+04	2.12E+04
60.	5.31E+00	6.35E+00	2.56E-05	1.88E+05	1.84E+05	1.84E+05	4.0E+04	1.90E+04
62.	3.35E+00	3.35E+00	1.41E-05	1.39E+05	1.40E+05	1.40E+05	4.0E+04	2.57E+04
64.	1.98E+00	1.72E+00	7.66E-05	1.10E+05	1.10F+05	1.10E+05	4.0E+04	3.20E+04
66.	1.13E+01	8.96E-01	4.67E-05	8.93E+04	9.00E+04	1.59E+05	4.0E+04	1.45E+04
68.	6.71E-01	5.19E-01	3.41E-05	7.75E+04	7.90E+04	1.53E+05	5.27E+04	1.25E+04
70.	3.75E-01	2.89E-01	2.66E-05	6.98E+04	6.98E+04	1.42E+05	5.66E+04	1.05E+04
72.	2.00E-01	1.51E-01	2.21E-05	6.30E+04	6.30E+04	6.34E+05	6.12E+04	9.00E+03
74.	1.03E-01	7.16E-02	1.92E-05	5.91E+04	5.99E+04	5.99E+05	6.12E+04	7.80E+03
76.	5.62E-02	3.35E-02	1.75E-05	5.62E+04	5.63E+04	5.63E+05	7.01E+04	5.90E+03
78.	2.88E-02	1.09E-02	1.52E-05	5.55E+04	5.57E+04	5.57E+05	6.44E+04	5.51E+03
80.	1.29E-02	1.99E-03	9.41E-07	6.66E+04	6.67E+04	1.03E+05	6.67E+04	6.66E+04
82.	5.51E-03	3.29E-03	5.53E-07	8.31E+04	8.40E+04	9.93E+04	8.40E+04	8.40E+04
84.	2.32E-03	8.53E-05	4.99E-07	8.47E+04	8.49E+04	8.49E+04	8.49E+04	8.49E+04
86.	1.00E-03	2.57E-05	4.98E-07	8.17E+04	8.20E+04	9.15E+04	8.20E+04	9.35E+03
88.	3.99E-04	6.33E-06	5.01E-07	7.88E+04	7.93E+04	8.11E+04	7.93E+04	9.93E+03
90.	1.67E-04	2.97E-06	5.00E-07	7.66E+04	7.74E+04	6.56E+04	1.00E+05	7.74E+04

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## **Appendix A**

**Steady-State Multi-Ion Disturbed D-Region Model Program**  
(Subroutine Initial, which contains input profiles of  
Q, M, T, minor neutrals and SI, has been omitted.)

```

5 C      40 - 90 KM IN INCREMENTS OF 2
C
C      78 REACTIONS
C
C      PROGRAM DREION(INPUT=65,OUTPUT=65,TAPE15=65,TAPE2)
10     COMMON NEUT(9,26),TEMP(26),M(26),Z(26),Q(26),SI(26)
      DIMENSION NION(8,26),NSPECI(8),PION(30,26),C(100),ESAVE(26)
      1      , ISPECI(30), INEUT(9), A(100), B(100),D(100),IREAC(100),
      2      JDUM(26), ITER(26), REAC(6)
      DIMENSION ICOEFF(26),EINT(26),SPINT(26),ICO_(2),EVENT(2)
15     REAL M,K,NEUT,NION
      INTEGER WATER,TPF,PCA
      REAL ICOEFF
      LOGICAL IONCF,DAY,FIRST,DIAGNOS
      DATA ICOOL/104 INT. E ,104 INT. SP /
20     C
      C      NALT=NUMBER OF ALTITUDES, ISTART IS INDEX OF STARTING ALTITUDE,
      C      NELE=NUMBER OF ELEMENTS IN PIION ARRAY TO BE COMPUTED
      C
      C      NELE=30
25     C      FIRST=.TRUE.

      C      READ IN COMPUTER RUN OPTIONS
      C
      C      READ 72, ISTART,NALT
30     72 FORMAT(2I5)
      C      IF(EOF(5LINPUT)) 99,73
      73 READ 69,SET,ISET
      69 FORMAT(A10,I5)
      PRINT 69, SET
      C
      35    74 READ 70,DAY,WATER,TPF,PCA,IONCF,DIAGNOS,CRIT,OD,EVENT(1),EVENT(2)
      70 FORMAT(1L2,3A2,2L2,2F5.0,2A10)
      C      IF(EOF(5LINPUT)) 99,71
      71 PRINT 67,DAY,WATER,TPF,PCA,IONCF,OD,CRIT,EVENT(1),EVENT(2)
      67 FORMAT(* DAY=*,L2,* H2O=*,A2,* TPF=*,A2,* PCA=*,A2,* IONCF=*,L2,
40     1      * OD=*,F5.0* CRITERIA=*,F5.0* PERCENT*,
      2      /*   *,2A10)

      C      DETERMINE SPECIE PROFILES AND OTHER PARAMETERS WHICH DESCRIBE THIS
      C      COMPUTER RUN - FOUND IN SUBROUTINE INITIAL
45     C      CALLI INITIAL(DAY,WATER,TPF,PCA)
      C
      C      PRINT 75 ,Z(ISTART),Z(NALT)
      75 FORMAT(5X,*ALTITUDE RANGE *, F5.0,* -,F5.1,* KM*)
      C      OD=0.
      C      IF(DAY) OD=1.
      C      IVES=0      $      NOS=VALT-ISTART+1

      C      OD= OPTICAL DEPTH FACTOR
55     C
      C      COMPUTE THE IONIZATION COEFFICIENTS FOR EACH ALTITUDE
      C
      C      SIGMA=1.0E-20
      C      IF(IONCF) 7,9

```

```

60      7 DO 6 J=ISTART,NALT
          H=(3032.*TEMP(J))/((6370.+(6370.+Z(J)))**2)
          ICOEFF(J)=4.7E-07*EXP(-(NEUT(2,J)*H*SIGMA*0))
          PION(30,J)=ICOEFF(J)*NEUT(5,J)
65      8 CONTINUE
          GO TO 15
       C      (NO)*I WILL NOT BE COMPUTED THIS RUN
66      9 NELE=29
15      15 CONTINUE
          TODAY=10H
70      RUNDY=DATE(TODAY)
          WRITE(?,150) RUNDY,SET
150     FORMAT(1H1,15X,*RUN DATE*,A10,15X,*REACTION SET OF*,A10)
          ALPHAD=4.0E-07
          ALPHAI=6.0E-08
75      TIME=10HDAY
          IF(.NOT. DAV) TIME=10HNTG4T
          WRITE(2,151) ALPHAD,ALPHAI,TIME,WATER,TPF,PCA,CRIT,
          1           EVENT(1),EVENT(2)
151     FORMAT(5X,*AD=*,1PE9.1,* AI=*,1PE8.1,2X,A10,*, H20=*,A2,
          1           *, TEMP=*,A2,*, PCA=*,A2,* CRITERIA=*,0PF5.0,* PERCENT*,
          2           *, EVENT *,2410)
          CRIT=CRIT/100.
          IF(IONCF) 11,13
11      11 WRITE(2,12) 3D,SIGMA
12      12 FORMAT(10X,*OPTICAL DEPTH FACTOR = *,F5.2,* SIGMA = *,1PE9.1)
13      13 NREAC=78
          IF(.NOT. FIRST) GO TO 19
          IF(PCA.EQ.2HLO.OR.PCA.EQ.2HHI) GO TO 18
          IF(PCA.EQ.2H72) 36,37
90      36 READ 16,(Q(I),I=1,25)
17      17 FORMAT(12F6.0)
16      16 FORMAT(1P7E10.2)
          IF(EOP(5LINPUT)) 99,18
37      37 READ 17,(Q(I),I=1,25)
95      95 IF(EOP(5LINPUT))99,18
18      18 CONTINUE
       C      READ IN CHEMICAL REACTIONS FROM TAPE15
       C
100     100 DO 20 II=1,NREAC
          READ(15,1) I,(REAC(L),L=1,6),A(I),B(I),D(I)
1      1 FORMAT(I4,A10,2A6,1X,A10,2A6,1PE9.2,0PF5.1,1D9.2)
          IREAC(II)=I
          IF(EOP(15)) 22,21
105     21 IF(ISET.EQ.0) GO TO 20
          WRITE(2,2) IREAC(I),(REAC(L),L=1,6),A(I),B(I),D(I)
2      2 FORMAT(I4,A10,2A6,1I4,A10,2A6,1PE9.2,0PF5.1,1PE9.2)
20      20 CONTINUE
          GO TO 19
110     22 NREAC=I-1
19      19 CONTINUE
          WRITE(2,805) NREAC
805    805 FORMAT(* THE NUMBER OF REACTIONS THIS RUN *,I10)
       ;

```



```

175      3
          DO 25 J=ISTART,NALT
          ITER(J)=0
25  JDUN(J)=3H N0
      3
180      3
          DO 100 J=ISTART,NALT
          25 JDUN(J)=3H N0
      3
          DO 100 J=ISTART,NALT
          25 JDUN(J)=3H N0
          DO LOOP 100 CALCULATES ALL THE POSITIVE IONS
      3
50  DO 100 J=ISTART,NALT
      IF(JDUN(J) .EQ. 3HYES) GO TO 100
      ITER(J)=ITER(J)+1
185      CALL RATECN(K,A,B,D,IREAD,TEMP,J,NREAD)
      IF(ITER(J) .GT. 1) GO TO 90
      PI0N(25,J)=NEUT(2,J)*(K(61)*NEUT(2,J)+K(62)*NEUT(4,J))
      IF(MAY) 51,52
51  PI0N(1,J)=SQRT(Q(J)/SI(J))
      GO TO 53
52  PI0N(1,J)=SQRT((PI0N(25,J)/(2.*ALPHAD))**2+1(J)/ALPHAD)
      1          -PI0N(25,J)/(2.*ALPHAD)
53  PI0N(2,J)=SQRT((Q(J)*(5.*NEUT(1,J)/ALPHAD+NEUT(3,J)/ALPHAI))/
      1          (5.*NEUT(1,J)+NEUT(3,J)))
      1
195      EINT(J)=PI0N(1,J)
      SPINT(J)=PI0N(2,J)
90  AISP=ALPHAI*PI0N(2,J)
      CALL NEGION(DAY,NION,K,PI0N(25,J),PI0N(1,J),J,AISP,PI0N(3,J))
      AISN=ALPHAI*PI0N(3,J)
200      CON1=K(8)*NEUT(1,J)+K(9)*NEUT(7,J)+K(42)*M(J)+DD*K(4)+AISN
      CON2=K(7)*NEUT(2,J)*M(J)
      CON4=NEUT(7,J)*(K(10)+K(11))+AISN+K(30)*PI0N(1,J)+DD*K(5)
      CON5=DD*K(4)+(DD*K(5)*K(9)*NEUT(7,J)/CON4)
      PI0N(4,J)=.9*Q(J)/(AISN+K(27)*PI0N(1,J)+CON2+K(6)*
      1          NEUT(5,J)-(CON2*(K(8)*NEUT(1,J)+K(42)*M(J)+CON5)/
      1          (CON1+K(28)*PI0N(1,J))))
      1
      PI0N(5,J)=PI0N(4,J)*(CON2/(CON1+K(28)*PI0N(1,J)))
      PI0N(6,J)=PI0N(5,J)*K(9)*NEUT(7,J)/CON4
      PI0N(7,J)=K(10)*NEUT(7,J)*PI0N(6,J)/
      1          (K(12)*NEUT(7,J)+AISN+K(30)*PI0N(1,J))
      PI0N(8,J)=PI0N(6,J)*K(11)*NEUT(7,J)/
      1          (K(31)*PI0N(1,J)+K(18)*NEUT(7,J)*M(J)+
      2          K(13)*NEUT(4,J)**2+AISN)
      CON1=K(14)*NEUT(5,J)
      CON2=K(32)*PI0N(1,J)+AISN
      PI0N(9,J)=(K(13)*NEUT(4,J)*NEUT(4,J)*PI0N(3,J))/
      1          (CON1+K(35)*PI0N(1,J)+AISN)
      CON3=K(15)*NEUT(7,J)
      PI0N(10,J)=(CON1*PI0N(9,J))/(CON3+K(36)*PI0N(1,J)+AISN)
      H2OM1=NEUT(7,J)*M(J)
      PI0N(11,J)=(PI0N(7,J)*K(12)*NEUT(7,J)+K(18)*PI0N(8,J)*H2OM1+
      1          PI0N(10,J)*CON3)/
      1          (K(32)*PI0N(1,J)+K(19)*H2OM1+AISN+
      1          K(16)*NEUT(6,J)*M(J))
      PI0N(12,J)=(K(16)*NEUT(6,J)*PI0N(11,J)*M(J))/
      1          (K(37)*PI0N(1,J)+AISN+K(17)*NEUT(7,J))
      CON1=K(21)*NEUT(6,J)*NEUT(4,J)
      CON2=K(22)*NEUT(7,J)
      SQN2=NEUT(4,J)*NEUT(4,J)

```

```

230      PION(13,J)=(.1*Q(J)+K(6)*NEUT(5,J)*PION(4,J)+PION(30,J))/  

1          (K(26)*PION(1,J)+CON1+AISN  

2          +(K(43)*SQN2-(K(43)*SQN2*NEUT(4,J)*K(51)/  

3          (K(44)*NEUT(6,J)+K(38)*PION(1,J)+AISN+K(51)*NEUT(4,J)))  

PION(14,J)=(K(43)*PION(13,J)*SQN2)/  

1          (K(44)*NEUT(6,J)+K(38)*PION(1,J)+AISN+(51)*NEUT(4,J))  

PION(15,J)=(CON1*PION(13,J)+K(44)*NEUT(6,J)*IDN(14,J))/  

1          (CON2+K(38)*PION(1,J)+AISN)  

CON1=K(23)*NEUT(7,J)*NEUT(4,J)  

PION(16,J)=CON2*PION(15,J)/(CON1+K(39)*PION(1,J)+AISN  

240      1          +K(45)*SQN2)  

PION(17,J)=(PION(16,J)*K(45)*SQN2)/  

1          (K(46)*NEUT(6,J)+K(40)*PION(1,J)+AISN)  

PION(18,J)=(PION(17,J)*K(46)*NEUT(6,J))/  

1          ((47)*NEUT(7,J)+(40)*PION(1,J)+AISN)  

245      CON2=K(24)*NEUT(7,J)*NEUT(4,J)  

PION(19,J)=(CON1*PION(16,J)+PION(18,J)*K(47)*NEUT(7,J))/  

1          (K(40)*PION(1,J)+CON2+AISN+(48)*SQN2)  

PION(20,J)=(PION(19,J)*K(48)*SQN2)/  

1          (K(49)*NEUT(6,J)+K(41)*PION(1,J)+AISN)  

250      PION(21,J)=(PION(20,J)*K(49)*NEUT(6,J))/  

1          (K(50)*NEUT(7,J)+K(41)*PION(1,J)+AISN)  

PION(22,J)=(CON2*PION(19,J)+PION(21,J)*K(50)*NEUT(7,J))/  

1          (K(25)*NEUT(7,J)+K(41)*PION(1,J)+AISN)  

G=K(34)*PION(1,J)+AISN+K(52)*M(J)  

255      PION(23,J)=(PION(11,J)*K(19)*H2OM1+PION(22,J)*K(25)*NEUT(7,J)+  

1          K(17)*PION(12,J)*NEUT(7,J))/  

1          (K(33)*PION(1,J)+K(20)*H2OM1*(1-K(52)*M(J)/G)+AISN)  

PION(24,J)=(PION(23,J)*K(20)*H2OM1)/G  

PION(26,J)=PION(3,J)/PION(1,J)  

260      PION(27,J)=Q(J)/PION(1,J)**2  

PION(29,J)=PION(3,J)+PION(1,J)  

100    CONTINUE  

300      IF(JUMP.EQ.2) GO TO 126  

265    C COMPUTE THE SUM OF THE POSITIVE IONS  

C  

DO 120 J=ISTART,NALT  

IF(ITER(J).GE.20) JDJN(J)=3HNO  

IF(JDUN(J).EQ.3HYES) GO TO 120  

270      ESAVE(J)=PION(1,J)  

PION(28,J)=0.  

DO 121 I=4,24  

121    PION(28,J)=PION(28,J)+PION(I,J)  

IF(ABS(1.-PION(29,J)/PION(28,J)).LE.CRIT) JDUN(J)=3HYES  

275      IF(JDUN(J).EQ.3HYES) GO TO 119  

PION(2,J)=.5*(ESAVE(J)+PION(28,J)+PION(3,J))  

118    PION(1,J)=.5*(ESAVE(J)+PION(28,J)/(1.+PION(26,J)))  

GO TO 120  

119    IYES=IYES+1  

NOS=NOS-1  

120    CONTINUE  

IF(DIAGNOS) 40,49  

40    J=ISTART  

      WRITE(2,269) Z(J),(PION(I,J),I=25,29),SPINT(J),PION(2,J),EINT(J),

```

```

285      1          PION(1,J),ITER(J),JDUN(J)
      IF(ITER(J) .GE. 20) 125,50
      49 CONTINUE
      ; IF(ITER(ISTART) .EQ. 1) GO TO 122
      DO 125 J=ISTART,NALT
290      IF(JDUN(J) .EQ. 3H NO) GO TO 50
      125 CONTINUE
      PRINT*, " THE SCORE IS ",IYES," YES AND ",NO, "NO"
      122 WRITE(2,200) (INEUT(I),I=1,9)
      200 FORMAT(//* ALTITUDE*,3X,9(A10),2X,*H*,9X,*TEMP*)
      295      DO 235 J=ISTART,NALT
      WRITE(2,240) Z(J),(NEUT(I,J),I=1,9),H(J),TE1*(J)
      240 FORMAT(0PF10.0,11(1X,1PE9.2))
      235 CONTINUE
      WRITE(2,273) ISPECI(1),ISPECI(3),(NSPECI(J),J=1,8)
300      273 FORMAT(//* ALTITUDE *,2X,11(1X,A10))
      DO 272 J=ISTART,NALT
      WRITE(2,274) Z(J),(PION(1,J),PION(3,J),(NION(I,J),I=1,8)
      274 FORMAT(F10.0,11(2X,1PE9.2))
      272 CONTINUE
305      IL=3
      DO 270 I=1,2
      IM=IL+1
      IL=IM+10
      310      IF(IL .GT. 24) IL=24
      WRITE(2,273) (ISPECI(J),J=IM,IL)
      DO 276 J=ISTART,NALT
      WRITE(2,274) Z(J),(PION(N,J),N=IM,IL)
      276 CONTINUE
      270 CONTINUE
315      WRITE(2,271) (ISPECI(J),J=25,29),ICOL(2),ISPECI(2),
      1          ICOL(1),ISPECI(1)
      271 FORMAT(//* ALTITUDE *,2X,9(1X,A10),2X,*Q*,7(,* ITER*)
      DO 275 J=ISTART,NALT
      WRITE(2,269) Z(J),(PION(I,J),I=25,29),SPINT(J),PION(2,J),EINT(J),
      320      1          PION(1,J),Q(J),ITER(J)
      269 FORMAT(0PF10.0,10(2X,1PE9.2),2X,15)
      275 CONTINUE
      ; IF(ITER(ISTART) .EQ. 1) GO TO 50
      FIRST=.FALSE.
325      GO TO 74
      99 CONTINUE
      CALL EXIT
      END

```

SUBROUTINE NEGION

```

1      SUBROUTINE NEGION(DAY,NION,K,LA,E,J,AISP,SUM)
2
3      SUBROUTINE NEGION COMPUTES THE CONCENTRATION OF NEGATIVE IONS
4
5      NEGATIVE ION SPECIES ARE STORED IN ARRAY NION
6
7      INDEX NION
8      1 02-
9      2 04-
10     3 C04-
11     4 03-
12     5 C03-
13     6 0-
14     7 N02-
15     8 N03-
9
10     COMMON NEUT(3,26)
11     DIMENSION NION(8,26),K(100)
12     REAL NION,K,LA,NEUT
13
14     LOGICAL DAY
15     IF(DAY) 1,2
16     1 D=1
17     GO TO 3
18     2 D=0
19     3 02SQ=NEUT(2,J)*NEUT(2,J)
20     X=K(77)*02SQ+K(80)*NEUT(3,J)
21     B=NEUT(1,J)*K(63)+K(64)*K(65)*NEUT(8,J)+K(66)*02SQ+K(91)+K(50)*NEUT(3,J)+AISP
22     T=K(73)*NEUT(1,J)+K(74)*NEUT(5,J)+K(75)*NEUT(9,J)+D*K(94)+AISP
23     W=K(71)*NEUT(1,J)+K(72)*NEUT(6,J)+AISP
24     V=K(68)*NEUT(3,J)+K(69)*NEUT(5,J)+K(70)*NEUT(1,J)+D*K(93)+AISP
25     U=K(78)*NEUT(1,J)+X+D*K(92)+K(79)*NEUT(8,J)+AISP
26     1   +K(81)*NEUT(3,J)
27     R=V*(U*W*T-D*K(94)*K(72)*NEUT(6,J)*X)
28     S=02SQ*(W*U*(K(66)*K(70)*NEUT(1,J)+U*K(66)*K(58)*K(72)*
29     1   NEUT(6,J)*NEUT(3,J)+V*K(64)*K(72)*K(77)*NEUT(1,J)*
30     2   NEUT(6,J))+V*K(72)*NEUT(5,J)*NEUT(3,J)*(J*K(50)+K(64)*K(80)*
31     3   NEUT(1,J))
32     4
33
34     40    NION(1,J)=02-
35
36     NION(1,J)=(V*U*W*R*E*LA)/(R*B*V*U*H
37     1   -J*R*K(66)*K(68)*K(71)*NEUT(1,J)*NEUT(3,J)*02SQ-
38     2   J*R*K(66)*K(71)*K*NEUT(1,J)**2-
39     3   S*V*NEUT(1,J)*(K(71)*X)*K(94)+J*W*K(73))-*
40     4   U*R*V*K(68)*K(71)*NEUT(3,J)*NEUT(1,J)
41     1   -W*V*K(64)*K(81)*NEUT(1,J)*NEUT(3,J)
42     6   -(S*W*V*K(81)*NEUT(3,J)*D*K(94))/R)
43
44     50    NION(2,J)=04-
45
46     NION(2,J)=(K(66)*02SQ*NION(1,J))/(
47     1   (K(67)*NEUT(6,J)))
48
49     NION(3,J)=C04-
50
51     NION(3,J)=(K(66)*02SQ*NION(1,J))/(
52     1   (K(68)*4EUT(3,J)+K(69)*4EUT(5,J)+K(70)*NEUT(1,J))

```

```

60      2      D*K(93)+AISP)
C
C      NION(5,J)=C03-
C
C      NION(5,J)=S*NION(1,J)/R
65  C
C      NION(6,J)=0-
C
C      NION(6,J)=(K(64)*NEJT(1,J)*NION(1,J)+D*K(94)*NION(5,J))/U
C
70  C      NION(4,J)=C03-
C
C      NION(4,J)=(K(68)*NEJT(3,J)*NION(3,J)+K(77)*NION(5,J)*02SQ+
1      NEUT(3,J)*(K(68)*NION(1,J)+K(80)*NION(6,J)))/W
C
75  C      NION(7,J)=N02-
C
C      C=(D*(K(96))/(D*(K(96)+K(97))+AISP)
C      NION(7,J)=(K(74)*NEJT(5,J)*NION(5,J)+C*(K(75)*NEUT(9,J)*NION(5,J) +
1      K(69)*NEUT(5,J)*NION(3,J)))/
2      (K(76)*NEUT(3,J)+D*K(95)+AISP-C*K(75)*NEUT(3,J))
C
C      NION(8,J)=N03-
C
C      NION(8,J)=(K(75)*NEJT(9,J)*NION(5,J)+K(76)*NEUT(3,J)*NION(7,J) +
85     1      K(69)*NEUT(5,J)*NION(3,J))/
2      (D*(K(96)+K(97))+AISP)
SUM=0.
DO 10 I=1,8
10 SUM=SUM+NION(I,J)
RETURN
END

```

#### SUBROUTINE RATECN

```

1      SUBROUTINE RATECN(K,A,B,D,IREAC,TEMP,IALT,NREAC)
DIMENSION K(1),A(1),B(1),D(1),IREAC(1),TEMP(1)
REAL K
DO 10 J=1,NREAC
5      I0=IREAC(J)
K(I0)=A(I0)*(TEMP(IALT)/300.)**B(I0)*EXP(D(I0)/TEMP(IALT))
10  CONTINUE
RETURN
END

```

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